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The 19th CDIO International Conference

Proceedings - Full Papers

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Editorial

The CDIO Initiative is an approach to designing innovative educational frameworks, aiming for educations that support students in developing the necessary professional skills required of a practicing engineer while simultaneously acquiring strong technical fundamentals This is done by providing students with dual-impact learning experiences that are based upon the lifecycle of an engineering project, the Conceiving-Designing-Implementing-Operating (CDIO) of real-world products, processes, and systems. Throughout the world, close to 200 institutions have adopted CDIO as the framework for curriculum development.

CDIO collaborators recognize that engineering education is acquired through programs of varying lengths and stages in a variety of institutions and that educators in all parts of this spectrum can learn from practiceelsewhere. Several times each year, CDIO collaborating institutions, engineering educators and researchers gather to exchange ideas and experiences, review developments, assess and further refine the CDIO approach.

The Annual International Conference is the key event for the CDIO community where CDIO practitioners from all over the world come together, share knowledge and promote the advancement of the practice of the CDIO initiative for producing the next generation of engineers. It includes presentations of papers as well as specialized seminars, workshops, roundtables, events, and activities.

The 19th CDIO International Conference took place in Trondheim, Norway, June 26-29, 2023, hosted by the Center for Science & Engineering Education Development (SEED) at the Norwegian University for Science & Technology (NTNU).

The main theme of the conference was **“Engineering education for a smart, safe and sustainable future".** The theme is present in the keynote presentations, paper presentations, roundtables, workshops, and the panel debate on the final day of the conference. The program covered many aspects of engineering education, such as sustainability, lifelong learning and change leadership. Specific topics covered were curriculum agility, emotion and reason in engineering education, digital transformations and of course aspects on operationalization of the CDIO Standards and the CDIO Syllabus.

The conference includes three types of contributions: Full Papers, Project in Progress contributions, and Extended Abstracts for Activities. The Full Papers fall into three tracks: Advances in CDIO, CDIO Implementation, and Engineering Education Research. All contributions have undergone a full single-blind peer-review process to meet scholarly standards. The Projects in Progress contributions describe current activities and initial developments that have not yet reached completion at the time of writing. The Extended Abstracts summarize the Roundtable Discussions and Workshops held at the event.

Initially, 216 abstracts were submitted to the conference. The authors of the accepted Full Paper and Projects in Progress abstracts submitted 128 manuscripts to the peer review process. During the review, 375 review reports were filed by 101 members of the 2023 International Program Committee. Acceptance decisions were made based on these reviews. The reviewers’ constructive remarks served as valuable support to the authors of the accepted full papers when they prepared the final versions of their contributions. We want to address our warmest thanks to those who participated in the rigorous review process.

A total of 78 educational institutions from 33 countries, representing 6 continents, were present during the conference. The total number of registered participants at the conference was 288.

This publication, which is available as an electronic publication only, contains the 85 accepted Full Papers that were presented at the conference, of which 3 are Advances in CDIO; 55 CDIO Implementation; and 27 Engineering Education Research. These papers have been written by 260 different authors representing 30 countries. Additionally, 21 CDIO Project in Progress contributions were presented at the conference but are not included in this publication. Also, a total of 33 collaborative contributions for activities in 17 Workshops, 12 Roundtable Discussions and 4 Working Groups took place, as well as a range of social events.

Note that the Conference Proceedings is SCOPUS Indexed.

We hope that you find these contributions valuable in developing your own research, curriculum development, and teaching practice, ultimately furthering the engineering profession. We also hope that you benefit through the truly unique community of practice that exists within the CDIO Initiative.

We wish all of you a wonderful CDIO experience!

Trondheim, June 30, 2023

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I Advances in CDIO

EDUCATION AS COMPLEX SYSTEM: NEED FOR MORE FORWARD-LOOKING CDIO PROGRAM EVALUATION

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ABSTRACT

This paper advocates for the explicit articulation of the needs for programs to engage in external and internal scanning within an educational context, to strengthen each program's positioning in responding to changes in its operating environment in a more timely and effective manner. It noted that the 12 CDIO Core Standards, in particular Standard 1 and Standard 12, did not state explicitly the need for Program Chair to undertake such exercises. In addition, Standards 9 and 10 also did not made clear that this should be a core competency of Program Chairs. This paper suggests that Program Chairs can learn from strategic planning management in the business world, using tools such as STEEP Analysis and SWOT Analysis. STEEP is the acronym for the five drivers of change that can affect an organization and its operations, namely Social, Technological, Economic, Environmental, Political; and SWOT stands for the acronym Strengths, Weaknesses, Opportunities and Threats that the organization is facing. In addition, due to the complex nature of education, with many stakeholders often with competing demands, a tool for analysis the relationship between these stakeholders is also needed. This paper firstly provides a brief introduction strategic planning in the educational context, followed by the use of STEEP Analysis and SWOT Analysis. It then shares the use of STEEP Analysis and SWOT Analysis alongside the CDIO Self-Evaluation process by way of 2 case studies for the Diploma in Chemical Engineering (DCHE): one in introduction of chemical product design (in 2007) and another on impact of Industry 4.0 on chemical engineering education (in 2018). The paper then proceeds to discuss a key learning point from the latest review of the DCHE curriculum initiated in 2020 to enhance coverage of sustainable development, which is the need to make sense of sustainability issues. This paper further posits that today's educational system is itself a complex system and efforts towards Education for Sustainable Development needs a more systematic approach to complement the CDIO Self-Evaluation in analyzing interactions and relationships between various change drivers and key stakeholders. To this end, the paper proposes one explores the Cynefin Framework, which had been used as a tool for sense-making when analyzing complex systems in various contexts. Lastly, this paper discusses the relative merits in the CDIO Framework in formalizing the use of external and internal scanning and developing competency for Program Chair in this area.

KEYWORDS

External Scanning, SWOT, Cynefin Framework, Sustainability, Core Standards 1 and 12

<u>NOTE</u>: Singapore Polytechnic uses the word 'courses' to describe its education 'programs'. A 'course' in the Diploma in Chemical Engineering consists of many subjects that are termed 'modules'; which in the universities contexts are often called 'courses'. A teaching academic is known as a 'lecturer', which is often referred to a as 'faculty' in the universities.

INTRODUCTION

New developments brought about by the Fourth Industrial Revolution (4IR), renewed emphasis towards sustainable development, on-going pandemic, etc; had created new demands and expectations for engineering education. Hadgraft & Kolmos (2020) had suggested that new types of engineering programs are required. In today's fast changing world, educators especially those tasked in managing programs – known in various capacities as Program Chair, Program Owner, Program Manager, etc – faced tremendous pressure to keep the programs up-to-date and remain relevant to meet key stakeholders' requirements. This term "Program Chair" will be used for this paper, as this is closest to the term "Course Chair" used in Singapore Polytechnic (SP).

CDIO Standards are a key part of the CDIO Framework, as they defined the distinguishing features of a CDIO program, by providing guidelines for educational reform, and serves as a tool for continual improvement (Crawley et al, 2014). The latest version of the standards (i.e. version 3.0) now comprises 4 optional standards in additional to the initial 12 standards, now designated as core standards (Malmqvist, et al, 2020). With regard to the 12 CDIO Core Standards, 2 stands out as being most relevant to program management: Core Standard 1 The Context, and Core Standard 12 Program Evaluation. These 2 standards set the stage for reviewing all the courses covered in a program with the aim of continual improvement. Application of these 2 standards requires the Program Chair to be well-versed with the challenges affecting the environment in which the educational institution operates in, that drives its educational objectives and outcomes.

The description for CDIO Core Standard 12 Program Evaluation, noted that:

> "*A system that evaluates programs against these twelve standards and any optional standards adopted, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*."

This is further elaborate as follows:

> "*Program evaluation is a judgment of the overall value of a program based on evidence of a program's progress toward attaining its goals. A CDIO program should be evaluated relative to these 12 CDIO Standards and any optional standards that it has adopted. Evidence of overall program value can be collected with course evaluations, instructor reflections, entry and exit interviews, reports of external reviewers, and follow-up studies with graduates and employers. The evidence should be regularly reported back to instructors, students, program administrators, alumni, and other key stakeholders. This feedback forms the basis of decisions about the program and its plans for continuous improvement*."

From the perspective of Course Chairs, who may not be involved in strategic planning or analysis of change drivers affecting education, the use of CDIO Standard 12 may appear to be rather "inward" looking, in that it emphasize the review of other core and optional standards, i.e. how these were used to drive curricular change. Any reference to external scanning is at best implied and EXPLICIT mention of internal scanning is absent. For example, in Core Standard 2 it was mentioned that learning outcomes are to be validated by program stakeholders, and the rubrics mentioned of review by internal and external stakeholders.

Several authors from the CDIO Community did reported on the needs to engage key stakeholders in driving curriculum changes (e.g. Gunnarsson, et al, 2022; Brink, et al, 2020; Edelbro, et al, 2017; Kans, 2016) but few made explicit reference to external scanning (e.g.

Kupthasthein, 2020). There appears to be a gap in the CDIO standards that addresses academic program management.

An important point worth remembering is that educational output (in terms of its graduates) will always be lagging in responding to new demand, and time is always needed to make changes to existing curriculum, obtain faculty buy-in, develop faculty capability, develop new learning resources, etc. With students spending 3-4 years in campus learning, the industries they meant to serve will not see any such graduates until at least 4 years later. It will always be a perpetual struggle to keep up to date and respond to external changes. A more “outward looking” CDIO Standards can help to mitigate this.

This paper advocates for the explicit articulation of the needs for programs to engage in external and internal scanning within an educational context, so as to strengthen each program’s positioning in responding to changes in its operating environment in a more timely and effective manner. In addition, due to the complex nature of education (Ghaffarzadegan, 2017), with many stakeholders often with competing demands, a tool for analysis the relationship between these stakeholders is also needed.

EXTERNAL AND INTERNAL SCANNING, SWOT ANALYSIS, CYNEFIN FRAMEWORK

In today’s VUCA (volatile, uncertain, complex, ambiguous) world, it is of vital importance for an educational institution to stay abreast of external changes that may affect their timeliness in preparing the young for a future that cannot be clearly defined. At the same time, educational institutions are facing several challenges, including a decline in government funding (which often translated into reducing headcount), changing student demographics, and a need to compete with the emerging models of higher education (virtual university, massively open online courses, etc) while keeping the essence of a traditional comprehensive university. Various stakeholders are now demanding increased justification and documentation of program outcomes. The effectiveness of educational institutions is therefore increasingly dependent on their understanding of the external environment and their capacity to forecast and respond to the changing external landscape (Lapin, 2004). Many educational planners are turning to the process of strategic planning widely used in the business world for help.

Strategic planning can help universities maintain stability in a changing environment and respond constructively to increasing competition or external threats (Goldman & Salem, 2015). Lerner (1999) noted that the following benefits of strategic planning to universities:
- Creates a framework for determining the direction a university should take to achieve its desired future
- Provides a framework for achieving competitive advantage
- Allows all university constituencies to participate and work together towards common goals
- Allows dialogue between participants, thus improving understanding of the organization’s vision, and fostering a sense of ownership of the strategic plan, and belonging to the organization
- Aligns the university with its operating environment
- Allows the university to set priorities

In the business world, tools for external scanning such as STEEP Analysis and SWOT Analysis are well known among management executives. STEEP is the acronym Social, Technological, Economic, Environmental, Political - the 5 drivers of change that can affect an organization and its operations; and SWOT stands for the acronym Strengths, Weaknesses, Opportunities and Threats that the organization is facing. These tools, contextualized for the educational setting, would be of tremendous benefits to Program Chairs. However, many are often not familiar with them. Furthermore, CDIO Core Standards 9 and 10 also did not address the question of faculty competency in academic program management.

External Scanning in Educational Context

A key step in the strategic planning process is that of external scanning (also often known as external analysis or environmental scanning). It is the process of ongoing tracking of trends and changes in an organization's internal and external environment that may impact on its operations, especially in the future. It focuses on the interaction of events, on how trends in one area may affect trends in another. In the corporate world, environmental scanning is an integral part of an organization's strategic planning process. It involves the systematic collection and interpretation of relevant data to identify external opportunities and threats that help shape the organizations' decision-making in formulating its responses.

External scanning is equally important in the educational context. Within the CDIO leadership, it had been extensively used in the review and revision of the CDIO Standards and Syllabus themselves. In the case of CDIO Standards, the impact of external changes to the context of engineering education was one of the main driver for the need of updating (Malmqvist, Edström, & Rosén, 2020). The review of the CDIO Syllabus and its subsequent revision follows from the revised standards. The revised syllabus specifically addressed the skills and attitudes needed for sustainable development, digitalization and acceleration (Malmqvust, et al, 2022).

External scanning is wider in scope than traditional data collection educational institutions typically engage in, e.g. demographic data of students, examination results from their secondary schools, etc. Like its corporate counterpart, this is because it is based on the assumption that major impacts on the education system can come from various sources. It is more concerned with anticipating the future than describing the present. It enables educators to predict the changes in its external operating environment that has the potential to impact of education on learners (Poole, 1991). The environment within which the scanning takes place can broadly be classified into various areas: S – Social, P – Political, E – Environment, E – Economical, T – Technological, and L – Legal. Correspondingly, there are various acronyms using some or all of these areas, e.g. PEST Analysis, STEEP Analysis, and PESTLE Analysis.

While the business world has devoted a great deal of attention to environmental scanning in their strategic planning process, it is only recently that any emphasis has been placed on such practices in school settings (Pashiardis, 1996). There are many models of strategic planning, but planning models at higher educational institutions are not as well represented in the literature as are planning models for economic and industrial organizations (Ford & Miers 2008). Hatch & Pearson (1998) describes the general techniques and sources available for environmental scanning in the educational context, the advantages and disadvantages of scanning, a checklist for evaluating the quality and usefulness of documents that might be used, and a perspective on the ethics of scanning. Dolence (2004) noted while higher education has attempted to adapt and adopt various business concepts and models for use in colleges and universities, the process of adapting business models to academic culture had not been smooth. He proposes the Curriculum-Centered Strategic Planning Model (see Figure 1) which he developed specifically for higher education.

Internal Scanning and SWOT Analysis in Educational Context

Dooris, et al (2004) noted that since most institutions of higher education share a similar mission and compete for these same objectives, an essential part of strategic planning involves shaping the institution in ways that ensure mission attainment by capturing and maintaining a market niche in the quest for resources, faculty, and students. Strategic planning therefore has both external and internal faces. The outward-looking nature of external scanning is complemented by an inward looking component, with the outcomes being reviewed to chart the strategic directions for the institutions and strategic plans formulated. This is shown in Figure 2. Formulating strategic directions and plans is often carry out with the aid of SWOT Analysis, shown in Figure 3 below.

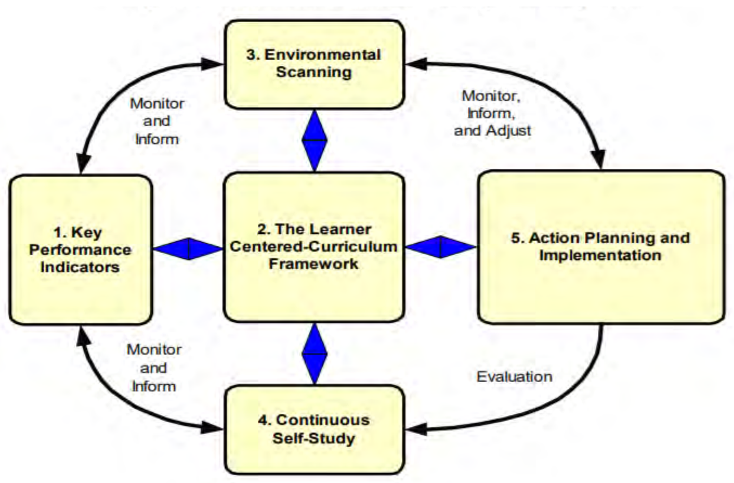

Figure 1. The Curriculum-Centered Strategic Planning Model (Dolence, 2004).

Figure 2. External and Internal Analysis and Strategic Planning (Morrison, 1993).

USE CASES: CDIO WITH EXTERNAL AND INTERNAL SCANNING

The Diploma in Chemical Engineering (DCHE) from Singapore Polytechnic (SP) had been adopting the CDIO Framework to guide its curriculum redesign process since 2006. The author, with his background in management on top of his engineering training had been using both external and internal scanning in appraising the relevancy of the DCHE curriculum when he was leading the CDIO Initiative in his school. The subsequent paragraphs in this section serve as use cases to illustrate how DCHE made use of STEEP Analysis and SWOT Analysis when it reviewed its 3-year curriculum vis-à-vis the CDIO Framework, notably Standard 12 Program Evaluation.

Figure 3. SWOT Matrix (Egger & Kent, n.a.)

Use Case No.1: Introduction of Chemical Product Design

Back in 2008, when DCHE first introduced its new curriculum revised following the adoption of CDIO, new modules related to chemical product design had been introduced (Cheah, 2010). The DCHE Course Management Team (CMT), then led by the author, had been looking for a a suitable framework to guide the curriculum redesign when it first recognized the changing paradigm in chemical engineering education that suggested the inclusion of chemical product design (Cheah, 2010). Such development promised to open up new career opportunities for chemical engineers, while at the same time, also demanded new competencies from students and graduates. The external scanning process involves studying various publications from the chemical processing industries, consulting companies such as PricewaterhouseCoopers, McKinsey, etc; as well as from academia, namely from journals such as *Education for Chemical Engineers*, and *Chemical Engineering Progress*.

The inclusion of chemical product design represents a significant change in the DCHE curriculum, which had been focused on covering competencies needed in traditional industry sectors serviced by the program, namely the oil and gas companies. All the lecturers from DCHE (the author included) are trained in the so-called 'classical' chemical engineering, where the various topics in the chemical engineering curriculum are oriented towards design of equipment and processes to serve the operations and control of chemical plants.

From a SWOT Analysis point of view, the emergence of chemical product design as a new discipline in chemical engineering can be seen as "opportunity" or "threat". The DCHE CMT saw this in the positive light, as it afforded opportunity for DCHE to distinguish itself from other similar programs offered by other polytechnics. This can be achieved by adding new modules into the DCHE curriculum and re-orienting the focus of final year student projects in DCHE. Internally, there are several "weaknesses" identified. A major one is the lack of product design capability within the ranks of DCHE lecturers. Another is the way existing final year projects are executed, which focus more in implementation and operation stages of the CDIO process. Hence, action plans need to be formulated to address the challenges posed.

The author therefore decided to engage the help of Dr. Geoff Moddridge from the Department of Chemical Engineering and Biotechnology, University of Cambridge, UK. Dr. Moggridge, along with Prof E.L. Cussler (University of Minnesota) were widely accredited with bringing chemical product design to prominence into the world of chemical engineering. To this end, he managed to bring Dr. Moggridge to Singapore to conduct a 1-week workshop on chemical product design in 2009. Modelled after his approach, a new module was introduced into the DCHE curriculum in 2009 itself. Another module was later added, which also introduce students to the use of design thinking in chemical product design, to put more emphasis on the “conceive” stage of chemical product design. In addition, changes were made to final year capstone project in accordance with the needs of CDIO Standard 5 Design-Implement Experiences. Lastly, a basic-level design-implement experience was introduced into Year 1, Semester 1 module entitled *Introduction to Chemical Engineering*, itself a new module added based on the guidance from CDIO Standard 4 Introduction to Engineering.

Subsequent external scanning recognized the increasing importance of education for sustainable development, as the modules in the DCHE curriculum were tweaked to support the process of conceiving, designing, implementing and operating a chemical product, process or system based on project-based learning via a “project spine” in the curriculum. This eventually lead to the use of chemical product design as the basis for education for sustainable development (for more details, see Cheah, 2014).

Due to the constraint in the number of pages for the paper, we will not go into details of the processes involved. Figures 4 and 5 showed examples of selected outcomes of our STEEP Analysis and SWOT Analysis respectively.

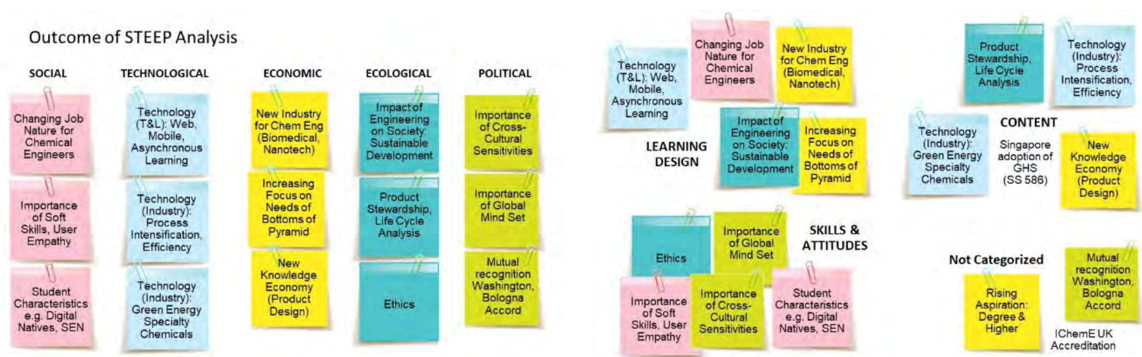

Figure 4. Use of STEEP Analysis for External Scanning and Categorization of Findings

Figure 5. Use of SWOT Analysis and Strategy Formulation, with an Example shown

Use Case No.2: Integration of Digitalization arising from Industry 4.0

More recently, in response to the emergence of 4IR; the DCHE curriculum once again undergo another round of major revision. As the work done had been covered in great detail elsewhere by Cheah & Yang (2018), only a concise summary will be provided here. Briefly, the CMT had undertaken an external scanning to ascertain what are the knowledge, skills and attitudes needed by the chemical processing industries introducing 4IR technologies into their operations. We used STEEP Analysis to identify key change drivers affecting the chemical processing industries. A key reference was the Skills Framework for the Energy and Chemicals Sector, Singapore Government’s response to the challenge of 4IR. We first established that the CDIO Framework was still relevant and useful: that the CDIO Syllabus in addressing the needs of 4IR and the CDIO Standards in providing guidance to design or redesign the curriculum. We then look for areas in the DCHE curriculum that need changes. The context of review is based on the Skills Framework for the Energy and Chemicals Sector, an initiative from the Singapore Government in response to 4IR. More specifically, we used the CDIO Syllabus to identify skills and attitudes needed such as making sense of big data, data fluency in particular via data visualization, virtual collaboration and self-directed learning. The latter is a key focus area for the Singapore Skills Framework. From the self-evaluation using CDIO Standards, we identified various aspects of teaching and learning that needs enhancement. These outcomes, combined with our SWOT Analysis, helped us to prioritize areas that needed the most attention.

Figure 6 shows selected examples of broad areas of improvement needed for DCHE, as “distilled” from the outcomes of STEEP Analysis and SWOT Analysis, and presented in the form of Self-Evaluation based on the 12 CDIO Standards.

<table>
<tr><td>CDIO Standard 3 – Integrated Curriculum</td><td colspan="3">A curriculum designed with mutually supporting disciplinary courses, with an explicit plan to integrate personal and interpersonal skills, and product, process, and system building skills</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 3</td><td>2012: 4</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Switched to sequential diploma structure since AY13/14. Problem-based learning piloted as assignment in Environmental Engineering in AY13. Introduced integrated laboratory, integrated assignment & integrated mid-semester test for Year 2. 22-weeks Enhanced Internship (EI) introduced in Semester 1, Academic Year (AY) 2015. To-date, 2 runs of EI had been completed. See also Standard 5.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To redesign the DCHE course structure to align to career map in the Energy & Chemicals Skills Framework (E&C SF), via a spiral curriculum, and closing gaps identified. To review EI for greater integration with the rest of DCHE curriculum. See also Standards 3 and 7 and discussion in main body of paper on approach taken.</td></tr>
</table>

<table>
<tr><td>CDIO Standard 12 – Program Evaluation</td><td colspan="3">A system that evaluates programs against these twelve standards, and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement</td></tr>
<tr><td>Rating from Self-Evaluation</td><td>2008: 2</td><td>2012: 3</td><td>2016: 4</td></tr>
<tr><td colspan="4">Brief Summary of Selected Efforts (from 2013 to 2016)
Integrated the CDIO self-evaluation process into Academic Quality Management System (AQMS) to help with course-level review, and cascaded the review down to module level. Diploma was successfully re-accreditation by Institution of Chemical Engineers (IChemE) UK in May 2017.</td></tr>
<tr><td colspan="4">Action Plans for Next 4 Years (2017 – 2020)
To obtain management approval for new spiral curriculum, to share with External Examiner, and to update IChemE UK on the changes made. To explore obtaining additional external validation of the revised curriculum, in relation to meeting E&C SF requirements.</td></tr>
</table>

Figure 6. Selected Examples of Areas of Improvement from STEEP and SWOT Analyses

As can be seen from Figure 6, one of these is the introduction of a spiral curriculum for DCHE (Core Standard 3). As the Institution of Chemical Engineers UK – as the professional body that accredits the program, Figure 6 also shows that we need to engage them on the change in course structure to the spiral curriculum format (Core Standard 12). Among the many changes we implemented based on the spiral curriculum is the integration of self-directed learning (see for example, Cheah & Wong, 2022). More recently, we also revised our coverage of sustainable development based on the Singapore Polytechnic initiative to introduce a Common Core Curriculum for all diplomas, as reported in Cheah (2021).

MOVING AHEAD (1): DEALING WITH COMPLEXITY RE: SUSTAINABILITY

In the latest round of curriculum review that started in 2020, the author investigated DCHE's coverage of sustainable development (Cheah, et al, 2022; Cheah, 2021). However, for this round, it was concluded that just using the STEEP Analysis and SWOT Analysis are not adequate to help us understand the challenges of sustainability issues in light of 4IR developments. Sustainable development had already been widely acknowledged as a "wicked problem" (Rittel & Webber, 1973). The recent changes due to 4IR not only have profound influence on engineering education, but can also affect sustainability efforts in positive or negative ways. For more discussion on this, see Cheah (2021). We therefore have a case of "sustainable development meets industry 4.0", a confluence of 2 challenges each of which on their own already presented significant challenges to engineering education. The goals of 4IR, which is first and foremost to improve manufacturing productivity, are not necessarily always compatible with that for sustainable development. We need to probe deeper when studying the impact of 4IR on sustainable development.

Once again, one can turn to the business world for a framework that can be used as a sense-making tool for strategic decision making in tackling sustainability issues: the Cynefin Framework (Figure 7). The conceptual thinking of the framework was drawn from knowledge management and complexity science; and was initially developed by Kurtz & Snowden (2003) and later by Snowden & Boone (2007).

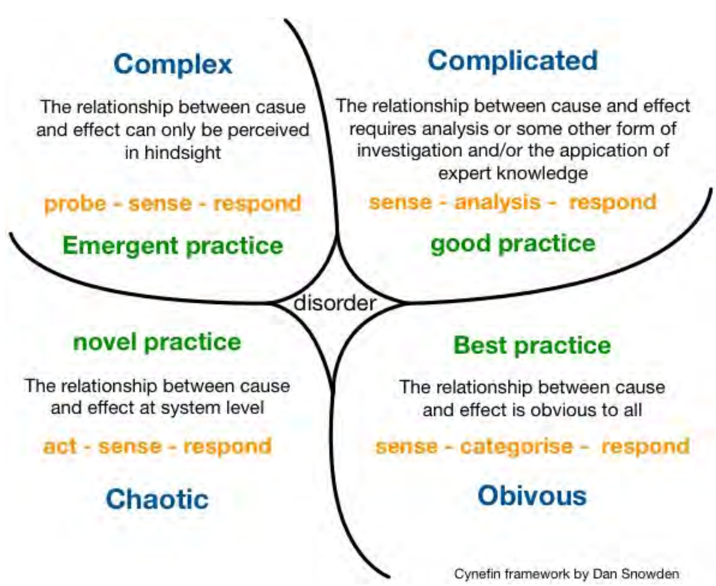

Figure 7. The Cynefin Framework

The Cynefin Framework offers a perspective of complex systems characterized with uncertainty; and concentrates on collective sense-making as a consequence of discourse. Table 1 provides explanations for the 4 categories of the Cynefin Framework – obvious, complicated, complex and chaotic – and how one can respond to each of them. The Cynefin Framework supports the use of both space and time to explicate the perspectives of different stakeholders, who populate the complex, socio-technical global contexts of the 21st century, making those perspectives visible to, and providing insights for, those involved in decision making (Hasan & Kazlauskas, 2009). Several authors had in fact used the Cynerfin Framework to investigate different aspects of sustainability issues, see for example in infrastructure design for climate adaptation (Helmrich & Chester, 2019), collaboration between partners in sustainability transitions, (Wigboldus, et al, 2019), and pedagogies in science, environment and health education (Zeyer, et al, 2019).

The Cynefin Framework had been suggested for use in educational systems (Hadgraft & Kolmos, 2020; Eskola, 2017; Gilbert, 2015). Hadgraft & Kolmos (2020) noted that "understanding of complexities derives from the dilemmas and the choices that are made in applying academic knowledge to contextual, real-world challenges". In the context of CDIO and education for sustainable development, this author will argue that the Cynefin Framework is useful to complement existing STEEP and SWOT Analyses, in helping Program Chairs making sense of challenges faced in redesigning one's curriculum for integrating sustainability issues.

Table 1. The Cynefin Framework (Kurtz & Snowden, 2003; Snowden & Boone, 2007)

S/N	Obvious	Complicated	Complex	Chaotic
Nature of problem	Obvious: once identified, it is immediately apparent	Specific expertise needed to analyze the situation	Large number of interdependent elements	No constraints, structure or discernible patterns
Cause and effect relationship	Clear patterns that occur repeatedly and predictably in the same form	Stable and existing but not immediately obvious	Not linear: dynamic and non-repeatable; constant flux and unpredictability; can only be understood retrospectively	Impossible to determine, even in retrospect, because things are continually changing at an exceptional rate
Solution / Right answer	Known and unmistakable, no rational person would disagree with your solution	Expertise – usually from different fields – are required to determine appropriate solution(s)	Elusive and not easy to ferret out; no right answers	Not recommended to jump to solution; but instead to take immediate action to steady and stabilize the environment
Practice	Best Practice exist: tried and tested formulae, recipes or templates	Good practice exists: approach can be developed and followed	Emergent: Solution emerge by interacting with the system (via small experiments) instead of analyzing or modelling it	Novel practice: objective is to move out from here into the Complex System
Suggested approach	Sense Categorize Respond	Sense Analyze Respond	Probe Sense Respond	Act Sense Respond

At the point of this writing, we have yet to make use of the Cynefin Framework. To the best knowledge of this author, use of Cynefin Framework for sustainable development is still in a nascent stage. The extant literature is still scarce. There appears to be huge potential for the use this framework for reframing diverse issues in many disciplines that are characterized by significant change and diversity (Elford, 2012). There is a good opportunity for CDIO to take the lead in addressing challenges in sustainable development by leveraging of the self-evaluation process guided by the use of CDIO Standards, supplemented by toolbox such as Cynefin Framework that analyse each sustainability issue under study.

We are looking for best practices of how it had been used in educational setting in general; and sustainable development in particular. We welcome members from the CDIO Community to explore and discuss the use of the Cynefin Framework in the context of education for sustainable development.

MOVING AHEAD (2): DOES CDIO NEED ANOTHER CORE STANDARD?

Given the points made in the above paragraphs, the last section of this paper explores the relative merits of having another CDIO core standard for external scanning. A simpler scenario would be not to have another separate standard, be it a core or optional one. This is for the simple argument to avoid proliferation of having too many standards. The need for external scanning can be made explicit in Core Standard 12, as part of continual improvement. The wording in the description for CDIO Core Standard 12 can be enhanced for example:

> "*A system that evaluates programs against these twelve standards and any optional standards adopted, via active scanning of the external and internal environment within which programs are offered to identify change drivers; and provides feedback to students, faculty, and other stakeholders for the purposes of continuous improvement*."

This can then be further elaborate upon in the detailed description and rationale for Core Standard 12. Specific areas that can be affected by the outcomes of such external and internal scanning can be provided here – for example new skills and attitudes as learning outcomes (Core Standard 2), increasing use of virtual learning spaces (Core Standard 6) and online learning be it synchronously or asynchronously (Core Standard 8), etc. The author opined that there is no need to make explicit the use of tools such as STEEP Analysis, SWOT Analysis or the Cynefin Framework in the Standard.

On the other hand, argument in favor of separate standard can be made if one looked into how the existing core standards were used: not all are used by all lecturers to the same degree. Core Standards 1, 3, 6 and 12 are most applicable at the program level, mainly referenced by Program Chairs to review one's program in setting a direction for the program in response to external and internal challenges, and for continual improvement. Core Standards 2, 7, 8 and 11 in particular were applicable to most, if not all, lecturers. Lecturers responsible for learning from projects with varying levels of complexity – with different combinations of elements of conceiving, designing, implementing and operating a product, process, system or service – in a program will be most influenced by Core Standard 5. On the other hand, Core Standards 9 and 10 are which concerns faculty competency in teaching and learning, are applicable to all lecturers and often required joint evaluation with Program Chairs to identify learning gaps; as well as the School or Department's training coordinator to identify appropriate professional development programs.

On this ground, a new standard on external scanning can serve as useful addition to the existing 12 Core Standards enhance the academic management aspect under the purview of Program Chairs. This provide exclusive focus to Program Chairs on what they need to, in steering the direction a program should take. This additional standard should make explicit references to Core Standards 1, 3, 6 and 12, so that they can look at the outcomes of external scanning in a holistic manner to drive program continual improvement.

In another development related to responding to changes in higher education institutions' external operating environment, Brink, et al (2020) presented the concept of curriculum agility to help institutions respond within a shorter timeframe than traditionally the case. With its 7 principles, the need for curriculum agility also has potential to be developed into a new CDIO Standard. In fact, the principle on Stakeholder Involvement reads: "Structures and procedures at the institution for identifying and prioritizing new needs, inviting stakeholder involvement in change processes to ensure an effective process for carrying out changes". Hence, it may also make sense to explicitly include external scanning in curriculum agility.

An Alternative to Standards: Use of Toolbox

Another approach that does not require using standards would be through some kind of toolbox for Program Chairs. There can potentially be various toolboxes for different applications, for which external and internal scanning is one of them. One such toolbox can provide greater guidance to Course Chairs than a standard can, and in greater granularity. It can, using STEEP Analysis as example, suggests sources of information, methodology for data collection, organization and categorization of data to provide useful insights, etc. The toolbox can provide guidance for SWOT Analysis in terms of criteria for prioritizing action plans. Likewise, it can also provide assistance in using the Cynerfin Framework in terms of probing questions to guide the implementation of education for sustainable development.

At this juncture, the author will prefer to have a separate document for external scanning, as as compared to embedding the requirement into Core Standard 12. The possibility of synthesizing this alongside development on curriculum agility is an attractive option. The alternative of using a toolbox is also irresistible to the author. This latter option is perhaps a more viable way to proceed without introducing additional element into the curriculum agility that is already in an advanced stage in terms of its development. There can be a suite of toolboxes, each toolbox addressing one aspect of challenges in teaching and learning, such as sustainable development. The author hence opined to consult the wider CDIO community on the relative merits on how best to proceed.

CONCLUSIONS

This paper presented an argument to extend the use of external scanning as part of professional development to better equip Program Chairs in carrying out their academic management functions. This suggestion is built on the grounds that developments in an education institution's external environment is moving much faster and move towards greater complexity. Even traditional tools such as STEEP Analysis and SWOT Analysis needs to be supplemented or complemented by additional tools to help Program Chairs make sense of the intricacies of different requirements from diverse stakeholders. To this end, the Cynefin Framework is suggested. To meet this requirement, a preference is indicated for a new standard, which can also incorporate another needs identified for curriculum agility.

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CURRICULUM AGILITY AS OPTIONAL CDIO STANDARD

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ABSTRACT

The concept of Curriculum Agility has been co-created in a series of sessions at CDIO meetings and conferences since 2018. Deliverables were a jointly generated definition, characteristics, a set of principles, and a self-mapping process on these principles. Using the Curriculum Agility concept offers guidance for CDIO programs and institutions in increasing the adaptability of their curricula based on the latest insights and developments in their discipline, continuously fulfilling the need of an ever more diverse student population and anticipating sudden societal changes. Curriculum Agility takes a holistic approach to considering conditions for proactive and timely curriculum development, including but not limited to enhancement of faculty competence. Although the success of CDIO implementation depends on this wider set of conditions that can drive, enable, or hinder change, this is currently not addressed in the CDIO standards. This paper proposes Curriculum Agility as an optional standard in the CDIO framework. It is a widely applicable, program-level concept including both educational and organisational aspects that addresses an important need in engineering education, and it is co-created within the CDIO community. Curriculum Agility is currently not sufficiently present or addressed in the existing standards. Therefore, this paper argues that Curriculum Agility as an optional standard and rubric will be a new useful tool in the CDIO toolbox.

KEYWORDS

Curriculum Agility, Optional Standard, Transformative Curriculum Change, Futureproof Engineering Education, Standards: 1-12

INTRODUCTION

Curriculum Agility is a conceptual framework that has emerged from work in the CDIO community. It refers to the ability of engineering programmes to be responsive to changes in industry and society, and in students' characteristics and needs, by proactively and in a timely manner adapting the curriculum's relevant organisational structures, learning outcomes, learning activities, and assessments.

This paper is a proposal to add Curriculum Agility (CA) as a new CDIO optional standard. When Malmqvist et. al. (2017) introduced the additional category of optional standards next to the core standards, it was to create a way for "*a controlled expansion of the CDIO standards, in consideration of the pedagogical developments within and beyond the CDIO community*". Hence, optional standards help make the CDIO framework more flexible, responsive to the various needs of the community, and it enables the community to take advantage of work on new frontiers. In short, optional standards were introduced to enhance the agility of the CDIO framework itself.

Malmqvist et. al. (2020b) presented a process for proposal, review, and acceptance of optional standards. The first step is to present the proposed optional standard at a CDIO conference, with a publication in the conference proceedings. The purpose of this paper is, accordingly, to be subject for general discussion and review in order to reach consensus in the community. Ultimately, it is the CDIO council that formally approves new optional standards.

FULFILLING THE OPTIONAL STANDARD CRITERIA

Optional standards should meet certain criteria, listed by Malmqvist et. al. (2020b). In this section, we will discuss how curriculum agility meets those criteria of importance for engineering education, novelty, program-level, wide applicability, and absence in the current standards, grouped and synthesised into two themes described below.

Addressing an important need in engineering education, not sufficiently addressed in the CDIO Standards, providing inspiration and guidance for CDIO programs and institutions in taking the lead

The CDIO approach is captured in two steering documents. *The CDIO Syllabus* (Malmqvist et al., 2022) is a comprehensive list of topics that can be addressed in engineering education to better prepare for professional practice. The document can be used by educators when customizing their programme learning objectives, or it can be used to analyse programs. *The CDIO Standards* are a set of aligned strategies for educational development, created to support the implementation of the CDIO Syllabus in an engineering programme. The standards *"define the distinguishing features of a CDIO programme, serve as guidelines for educational reform, enable benchmarking with other CDIO programmes and provide a tool for self-evaluation-based continuous improvement*" (Malmqvist et al., 2020a).

With regards to the function of providing guidelines for educational reform, Standard 1 is about deciding to educate graduates for professional practice, hence establishing the need for educational reform. Then, Standards 2–8 and 11–12 specify strategies for curriculum and course development, and evaluation. Interestingly, Standards 9 and 10 are of a somewhat different character, as they address the need for enhancing faculty competence with regards to the desired changes in what to teach and how to teach. They can be seen as a recognition of conditions that can drive, enable, or hinder change.

However, over decades of experiences of curriculum development, members of the CDIO community have many times found that, vital as it is, faculty competence is not the only necessary consideration. Other conditions that can drive, enable, or hinder CDIO implementation are related to (the perceptions of) all kinds of legislation, accreditation schemes, regulations on every level, institutional processes, bureaucracy, governance, organisational structures, procedures, administrative practices, leaders and managers, power structures, traditions, and culture. Similar to how one tends to notice headwind more than tailwind, the quickest association is to think of these aspects as sources of barriers. However, it is equally true that they can likewise create forces that are highly conducive. They can therefore also be seen as tools or resources that can be mobilized in favour of the work.

The conceptualisation of Curriculum Agility is an attempt to address conditions for CDIO implementation with a more holistic approach, including but not limited to enhancement of faculty competence. Although CDIO implementation depend on these conditions, they are currently not addressed in the CDIO standards. Curriculum Agility is therefore an important extension of the CDIO framework. It aims to inspire and guide those who want to innovate their engineering education but meet obstacles and challenges along the way. The Curriculum Agility standard and rubric will be a new useful tool in the CDIO toolbox. Assessing the conditions for curriculum change is a first step to adopt CDIO productively. It will be even more necessary to enable any transformative curriculum innovations.

A novel, widely applicable program-level pedagogic approach, developed within the CDIO community, and reflecting ongoing development in several CDIO programs

The Curriculum Agility concept has been created in a joint pursuit to understand what is needed for a programme to be able to innovate its curriculum, whether it is incremental or transformational innovation. CA is directed at the programme or curriculum level, focusing on the conditions for agile development of the programme. However, those conditions are also shaped by factors on higher levels, and therefore CA also reaches out to the institutional level, and sometimes beyond.

The co-creation process started at the 14th CDIO International Conference in Kanazawa (Hallenga-Brink et al., 2018). Between 2018 and 2023, CA has continuously been co-defined, co-created, and co-evaluated during CDIO conferences, regional meetings, and fall meetings, see column 2 in Table 1. Each time, different groups of CDIO members participated in the Curriculum Agility workshops, roundtables and working group sessions, as indicated in column 3 of Table 1. The participants' geographical diversity becomes apparent in column 4. They were considered engineering education experts and practitioners in focus-group sessions, each contributing to the ultimate end result. In column 5, the preliminary results of each session are indicated, which led to the concept as it is presented in this paper.

Table 1. The co-creation of the concept of Curriculum Agility.

	Meeting/ Conference, Date	**Session format, Title and, reference if accessible**	**Participants, Nationalities**	**(Preliminary) results after analysing the session outcomes**
1	14th International CDIO Conference at Kanazawa Institute of Technology, Japan, July 2018	Workshop: Developing A Rubric for Self-Assessment of Curriculum Agility	18 participants: From Australia, Canada, Denmark, France, Ireland, Japan, the Netherlands, Northern Ireland, Norway, Russia, Sweden, UK, USA	The name Curriculum Agility for what is needed for a HEEI to be able to transform curricula, 3 characteristics and four concepts for the definition of CA, of which one was chosen)
2	Regional CDIO meeting EU&UK/I, CESI Graduate School of Engineering La Rochelle, France, January 2019	Working lunch: Curriculum Agility	20 participants: From Denmark, France, Iceland, The Netherlands, Russia, Sweden, Tunisia, UK	Collection of important elements of CA, of good practice examples and of barriers for CA
3	15th International CDIO Conference, Aarhus University, Denmark, June 2019	Working group day: Self-Assessing Curriculum Agility	11 participants: From Indonesia, the Netherlands, Norway, Sweden, UK	A second prototype with refined definition of CA and the first seven principles of CA
4	CDIO EU & UK/I Regional Meeting, NTNU Norwegian University of Science and Technology, Trondheim, Norway, January 2021	Online Workshop: Curriculum Agility Principles, what do we prioritize and why?	14-25 active participants of 29 in total: From Denmark, the Netherlands, Norway, Sweden, Switzerland	Examples of CA activity at HEEIs pre and during pandemic and testing the value of the principles in light of the pandemic. Discussion on the culture of change, resulting in a sharped description of this principle
5	17th International CDIO Online Conference, Chulalongkorn University, Bangkok, Thailand, June 2021	Online roundtable: Roundtable on Curriculum Agility (Brink et al., 2020)	19 participants: From France, Japan, The Netherlands, Norway, Singapore, Spain, Sweden, Thailand, Tunisia, UK	The third iteration of the prototype, plus paper published in the proceedings of the conference on the seven principles of CA, validation and tweaks in definitions and wording
6	Frontiers in Education 2021 Envisioning Convergence in Engineering Education, University of Nebraska - Lincoln, College of Engineering, USA, October 2021	Hybrid Special Session: Curriculum Agility: Responsive organization, dynamic content, and flexible education (Brink et al., 2021)	8-10 active participants of 13 in total: From Canada, The Netherlands, Sweden, USA	The fourth iteration of the prototype, adding an 8th principle to the CA model, additional stakeholders based on cultural/regional differences.
7	CDIO Asian Regional meeting, Australian College of Kuwait, October 2021	Online interactive keynote: Curriculum Agility and the impact of the pandemic on its bears on the road	21-25 active participants from 107 in total: From the Middle East and the whole of Asia (affiliations were hidden)	Validating outcomes plus a fifth prototype of the CA model, with a ninth principle added. A pre-pilot approach to self-mapping, to be tried out at 1 university
8	The 18th Worldwide CDIO Conference, Reykjavik University, Iceland, June 2022	Working group day: Curriculum Agility - Self-Assessment on the Curriculum Agility Prin ciples	16 participants: From Estonia, France, The Netherlands, Norway, Sweden, UK	The sixth iteration of the prototype of the CA model, based on sixteen different principles configurations, 10th principle added and a 4th characteristic. Plus, self-mapping method proposals.
9	CDIO Fall Meeting in Turku, Finland November 2022	Fall meeting workshop: Bears and change agents… Curriculum Agility Workshop	9 participants: From Finland, Norway, the Netherlands, Singapore, Sweden	The 7th, tweaked prototype and visualisation of the CA model, as presented in this paper, including an extensive list of stakeholders and first rubric description
10	CDIO EU/UK Regional Meeting in Canterbury, UK, January 2023	Working Group meeting: Curriculum Agility	9 participants: From Ireland, Finland, Sweden, UK	The rubric description and a concept for optional standards as horizontals of the core standards
11	The 19th Worldwide CDIO Conference, NTNU, Trondheim, June 2023	Working Group Day: Curriculum Agility Working Group: The Self-Mapping Pilot	Expected participants From: France, India, Norway, The Netherlands, Sweden, UK	Expected: refined self-mapping method after testing it in 10 universities, publication for the next conference

In this continuous series of co-creation sessions, different CDIO members from different regions and engineering disciplines joined each time with a fresh look on the intermediary results that were presented for them to work with. A core group of co-creators remained active throughout the process and included outcomes of each former session into a new 'prototype' and a new plan for the next session. This process was led by the first author, as part of her doctoral studies. The diversity of the participants assured a pluralist angle on the resulting concept of Curriculum Agility. One session was held outside the CDIO community, for validation purposes.

Throughout the sessions, the design thinking steps of empathising, defining, ideation, prototyping and testing/validating came back in non-linear iterations, turning it into what it is today. For instance, when the model still had seven principles, it was mapped to the CDIO Standards 2.1 (Brink et al, 2020). The version presented in this paper has ten principles and is mapped to the CDIO Standards 3.0. The work triggered ongoing developments in several CDIO programs. The widespread interest in CA has shown that it is of importance to all engineering and design disciplines. In line with the idea that it is based on, agility, the authors warrant the model will continue to develop through time, but at this point it is stable enough to be offered to the whole CDIO community.

THE OPTIONAL STANDARD OF CURRICULUM AGILITY

In Figure 1, Curriculum Agility is portrayed by its definition and its four characteristics *flexible education, dynamic teaching contents, a responsive organisation, and continuous development of all staff*. The ten principles of Curriculum Agility shown are divided over and sometimes covering both the two main categories of organisation and education.

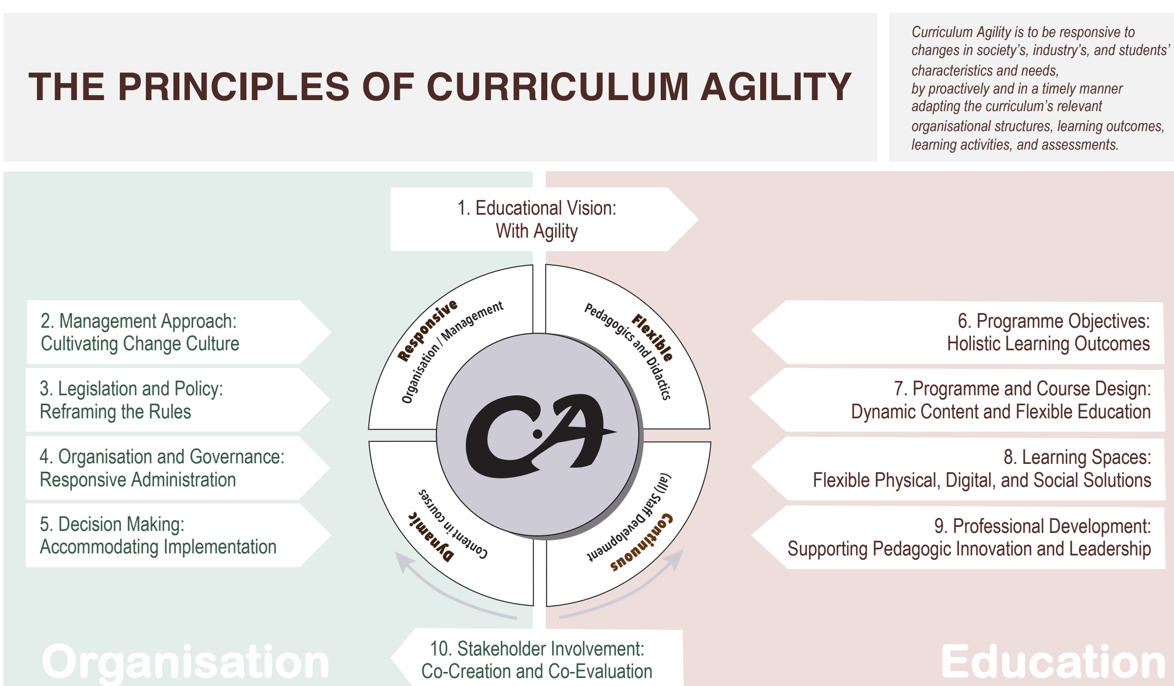

Figure 1. Curriculum Agility and its definition, characteristics, and principles

For the optional standard of Curriculum Agility, the program applies the four characteristics of Curriculum Agility in the adoption of the CDIO principles as the mechanism to proactively and timely adjust or alter the curriculum, adapting to the latest demands in engineering education (addition to Standard 1).

A program's goals and learning outcomes are recurringly fine-tuned on the shortest timespan allowed by the institution's policies to the latest version of the CDIO syllabus, to changes in technology and other disciplinary developments, and to relevant developments in society and in student characteristics (how to manage standard 2 with agility).

The learning contents of a program's integrated curriculum, which include but are not limited to personal and interpersonal skills, and product, process, system, and service building skills, are regarded as being dynamic and are altered when needed due to changes in technological and disciplinary shifts, developments in society, and changes in students' needs, (how to keep standard 3 updated), and consequently adjusted to what is needed for the different students' introductory engineering courses (how to keep standard 4 updated) and in the authentic, contextualised learning activities in collaboration with industry during the program's projects (how to keep standard 5 updated), adding interdisciplinarity in integrated learning experiences (addition to standard 7), or even trans-disciplinarity.

A program should have pedagogic and didactic flexibility built into its curriculum to be able to tailor to this dynamic interdisciplinarity (addition to standard 7), but also to meet diverse students' needs in a personalised way (beyond standard 8). A flexible education is supported by flexible physical and digital learning space configurations, such as hybrid teaching (simultaneously on-site and online), and authentic learning environments in industry or society, but also by flexible social learning spaces, such as student ownership of collaboration/group formation and reciprocal learning interaction (addition to standard 6). The way that students are assessed has to be equally flexible, personalized, and authentic to be in line with the flexible pedagogics and didactics (standard 11).

In this optional standard, the program is not only enhancing disciplinary faculty competence and teaching competence of the academic staff that teaches on the program, but rewards pedagogic leadership and innovation, amongst others by means of scholarship of teaching and learning (SoTL) (beyond standard 10). The program also expedites enhancement of all academic, supportive, and administrative staff involved in decisions to make changes in the curriculum (beyond standards 9 and 10). One fundamental way to enhance the competency of all staff is by inclusive, participatory curriculum refinement, (re)design, and innovation processes, in design-thinking co-creation with all relevant stakeholders within and outside the university. This approach adds feedforward about the program's quality to the feedback mechanisms as suggested in core standard 12, making it possible to adjust education (co-creation of and during learning) to the needs of its participants (beyond standard 12).

The former paragraph relates to the fourth characteristic of Curriculum Agility, a responsive organisation, which is an important prerequisite as well as facilitator for the curriculum changes that a higher education institution wants to make while adopting the CDIO framework. Cultivating a change culture within the organisation, openness to exploring and reframing the rules that drive university policies, creating administrative agility, and accommodating implementations are all important principles of Curriculum Agility.

Appendix 1 contains the proposal for the full description, rationale, and rubric of the optional standard of Curriculum Agility.

DISCUSSION

In the previous section, the supplements to the Core Standards have four appearances: Addition to Standard X, How to Manage Standard X, How to Keep Standard X updated, and Beyond Standard X. The latter category was first used in one of the transformative curriculum innovation cases that led to the start of the Curriculum Agility process (Hallenga-Brink, 2018) (Hallenga-Brink & Sjoer, 2017) and which used the twelve core standards of CDIO as a basis for the innovation process. Here it was concluded that for CDIO-standard related curriculum changes that prove more transformative in the context that they happen in, something more is needed. This ‘something more’ is now covered by the Optional Standard of Curriculum Agility.

Curriculum Agility supplements all the core standards of CDIO. Therefore, this paper suggests it is considered as a ‘horizontal’ under the twelve core standards. There are existing and will be future optional standards that have this same structure, such as the Sustainability standard. Curriculum Agility also adds new elements to the CDIO framework, on the organisational aspects of education. It appears to lie close to standard 12, but when comparing the two standard descriptions, Curriculum Agility implies pro-active, co-creation with stakeholders, and not just providing feedback to them. It implies rethinking the goals, not just evaluating whether CDIO goals are reached. And it includes adaptation of the organisational structures of the programme, not just the programme itself.

Curriculum Agility can be seen as ‘the motor oil of curriculum change’. Being developed by, within, and for the CDIO network, it has been carefully set up to serve all CDIO members as an optional standard.

Future developments

In line with the CDIO standard format, the evaluation of Curriculum Agility is captured in one rubric. However, higher education institutes may already do well on certain aspects of Curriculum Agility, whereas other aspects need more attention. To be able to identify what aspects to focus on and how to work on increasing the Curriculum Agility at one’s institute effectively, a more in-depth self-mapping tool will be introduced in the near future. With this tool, the institute will be guided to reach rubric levels 1 and 2, co-evaluating and co-creating throughout the layers of the organisation and with multiple stakeholders. A pilot of this method is discussed at the working group session at the CDIO Conference in Trondheim.

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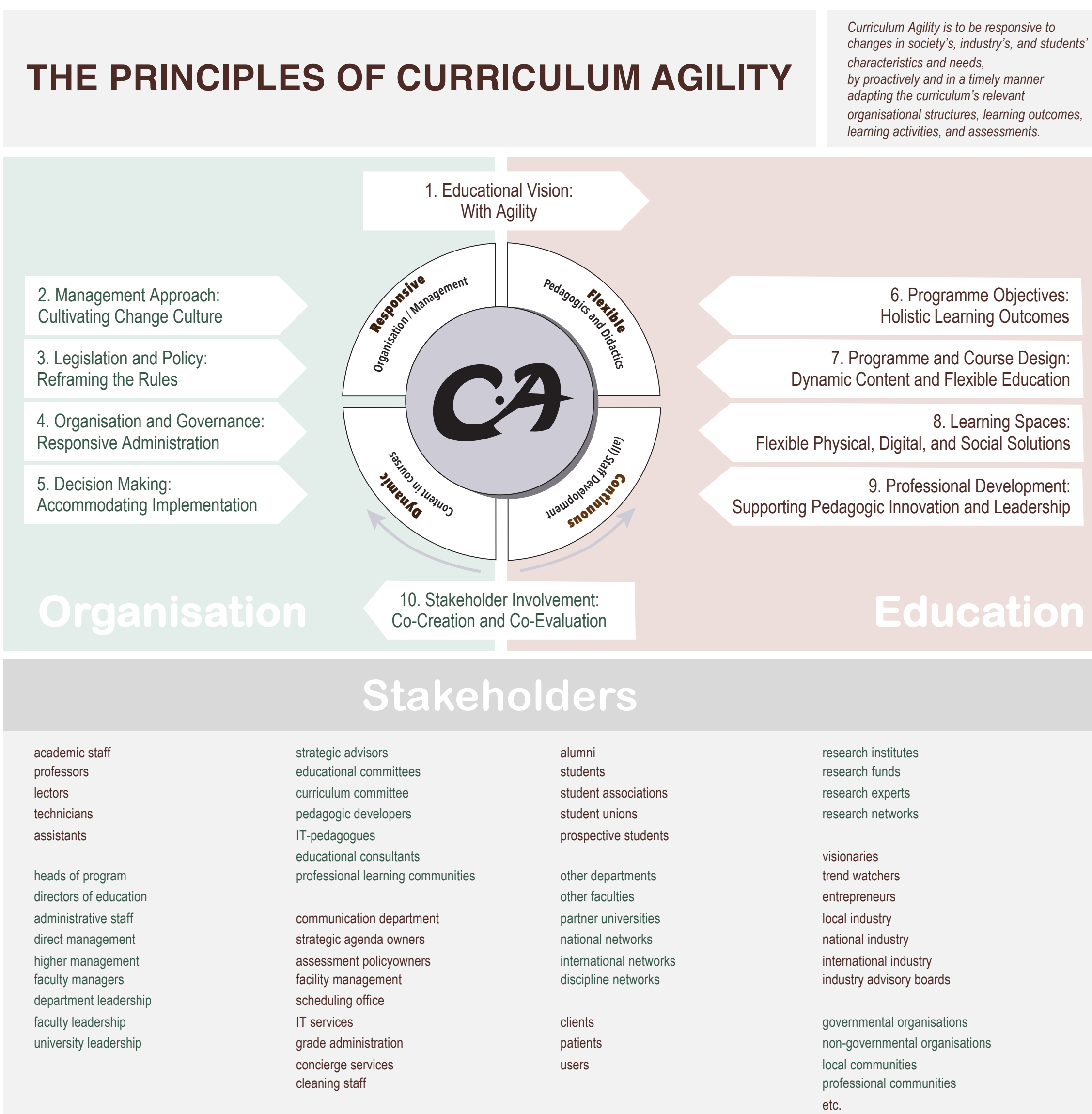
THE OPTIONAL STANDARD FOR CURRICULUM AGILITY

Characterisation

Curriculum Agility

Engineering programmes that are responsive to changes in industry and society, and in student characteristics and needs, by proactively and in a timely manner adapting the relevant organisational structures of the curriculum, as well as the learning outcomes, learning activities, and assessments.

Description



Rationale

In higher engineering and design education, there is a growing willingness and need to carry this responsibility of constantly adapting the curricula to the fast changes in technology and society. The causes for transformative curriculum changes vary widely and can be both economically and ethically driven. For instance, in certain engineering disciplines some knowledge & skills become obsolete shortly after students finish their studies. This calls for the need to dynamically change the contents of learning and keep a close eye on when those changes are solicited. Flexible education and responsive governance are necessary to deal also with sudden, impactful changes in society (as experienced during the pandemic). Student populations become increasingly diverse due to other changes in society. Norms have changed, bringing about developments such as increased accessibility and the focus on equality, diversity, and inclusion in accepting and supporting students' learning path while in university. Other drivers are globalisation, decolonisation, and the increasing need for lifelong learning opportunities as the general population on average gets older and has to work longer. Behind many of these developments lie changing values in our society and in individuals. Sustainability and ethics change the objectives and approaches of the engineering and design professions to the core, and it adds complexity that students need to learn how to deal with, often in interdisciplinary or even transdisciplinary ways. This in its turn adds complexity and wickedness to the curriculum design, making transformative curriculum changes a must. And for that, the higher education institution needs Curriculum Agility.

Rubric for self-assessment

0	There is no agility in the curriculum design, organization, and development processes
1	There is awareness of the need for adopting Curriculum Agility by means of a holistic approach involving academic, technical, managerial, and administrative staff in co-creation with all key stakeholders.
2	There is a plan on institutional level to widely introduce and implement continuous curriculum review and enhancement and do this in a holistic, co-creational approach with relevant stakeholders. CA Principles have been prioritized.
3	There is documented evidence of an integrated organizational system for responsive, dynamic, and flexible curriculum design and its continuous development, including facilitating academic, technical, and administrative staff continuously in their congruent developments.
4	There is documented evidence of ongoing improvements and adjustments in the curriculum design at program level and module level. Developing, teaching, and administrative staff are recognized and merited for their efforts in Curriculum Agility.
5	There is a cyclical and evidence-based co-creation and co-evaluation system of both feedforward and feedback in place, involving all stakeholders, which continuously feeds the curriculum development processes and decisions.

EVALUATING AND ENHANCING THE STATUS OF SUSTAINABILITY IN ENGINEERING EDUCATION

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ABSTRACT

When the optional CDIO Standard for Sustainable Development was introduced in 2020, the CDIO community was encouraged "*to document the work and share their experiences, in particular reflecting on the usefulness of the new standards for future refinement and development*". This paper is a response to that call, providing insights in how this optional Standard has been used for evaluating and enhancing the status of sustainability in the *Civil Engineering and Urban Management* program and *Electrical Engineering* program at the KTH Royal Institute of Technology. Details are shared on how sustainability is integrated in the programs, and opportunities and barriers for enhancing the status of sustainability in the two programs, and in engineering education in general, are discussed. The paper concludes that the CDIO Standard for Sustainable Development provides a framework and terminology for dialogue and collaboration, within as well as between programs, that can be used for driving change, from an add-on approach, through integration approaches, towards transformative approaches to sustainability in engineering education.

KEYWORDS

Sustainability, Sustainable Development, Integration, Program Evaluation, Program Development, Standards 1-5, 8, 11, 12, Optional Standard for Sustainable Development

INTRODUCTION

Through recent revisions, the CDIO Standards and the CDIO Syllabus have been updated to better promote and guide the integration of sustainability and sustainable development in engineering programs (Malmqvist et al 2020a&b, 2022). Aspects of sustainability and sustainable development have been included in several of the updated twelve "core" CDIO standards. To further emphasize the role of sustainability and provide inspiration and guidance, one of the new "optional" CDIO standards, that have been introduced as part of the CDIO Standards 3.0, specifically addresses sustainable development. When this new optional CDIO Standard for Sustainable Development (hereafter for simplicity referred to as *the SD Standard*) was introduced, the CDIO community was encouraged "*to document the work and share their* *experiences, in particular reflecting on the usefulness of the new standards for future refinement and development*" (Malmqvist et al. 2020b). One response to that call was presented in Rosén et al. (2021), where the SD Standard was put to test in an institution-wide evaluation of a large number of programs at the KTH Royal Institute of Technology. A set of indicators were introduced to facilitate the application, and some modifications were proposed to the SD Standard rubrics. Based on the experiences from that application, KTH has now implemented the SD Standard in their new internal sustainability objectives for education (KTH 2021). The present paper is yet another response to that call. While Rosén et al. (2021) concerned the operationalization of the SD Standard and presented an overview evaluation of 15 programs, the present paper shares and analyzes details for two of those programs and, in addition, discusses opportunities and barriers to enhancing the status of sustainability in the two programs and in engineering education in general.

THE CDIO STANDARD FOR SUSTAINABLE DEVELOPMENT

The SD Standard has the same format as all CDIO Standards and is formulated in terms of: a *characterization*; a *description*; a *motivating rationale*; and *rubrics* for self-evaluation. For the convenience of the reader of this paper, the *description* and the *rubrics* with the slight modifications proposed in Rosén et al. (2021) are here reproduced in Box 1 and Box 2. As seen, the SD Standard, for example, emphasizes the importance of sustainability being progressed through the program with an early introduction and several following mutually supporting courses, to provide students opportunities to acquire and develop not only sustainability *knowledge*, but also sustainability *skills*, *attitudes*, and *key competencies*.

Box 1: The SD standard description (Malmqvist et al 2020b).

The program emphasizes environmental, social and economic sustainability in the adoption of the CDIO principles as the context for engineering education. Sustainability related knowledge, skills and attitudes, are explicitly addressed in program goals and learning outcomes. Aspects of sustainable development are integrated in several mutually supporting disciplinary courses and projects, possibly in combination with specific sustainability courses. Concepts of sustainability, potentials and limitations of science and technology and related roles and responsibilities of engineers, are established at an early stage of the education. Design-implement experiences provide students with opportunities to apply and contextualize sustainability knowledge, skills and attitudes, both in the development of new technology and in the reuse, redesign, recycling, retirement, etc., of existing technology. Physical and digital learning environments enable interdisciplinary and transdisciplinary collaborative learning and interaction with various external stakeholders. Sustainability learning experiences are integrated with the learning of disciplinary knowledge, personal and interpersonal skills, and product, process, system and service building skills. Active experiential and transformative learning activities develop students' key competences for sustainability. Enhancement of faculty competences for sustainability and related teaching competences is actively promoted. Approaches appropriate for assessing sustainability related learning outcomes are implemented. The integration of sustainable development is evaluated by students, faculty, industry, and societal stakeholders, and in relation to relevant UN and other frameworks.

Box 2: The slightly modified SD Standard rubrics proposed in Rosén et al (2021).

1) Minor sustainable development learning experiences are implemented in at least one course and needs and opportunities for extended integration of sustainable development have been identified. 2) At least two sustainable development learning experiences, where at least one is substantial, are implemented and there is a plan for extended integration of sustainable development. 3) There are explicit program goals and intended learning outcomes considering knowledge as well as skills related to environmental, social, and economic aspects of sustainability, and students learning towards these goals and outcomes are supported by at least four sustainable development learning experiences, where at least two are substantial, including an introduction early in the program. 4) The integration of sustainable development is pervasive, well adapted to the program context, promoting progression of knowledge, skills, attitudes, and key competencies for sustainability, and there is documented evidence that students have achieved the related intended learning outcomes. 5) The SD Standard is fully implemented.

BRIEF OVERVIEW OF THE TWO CASE PROGRAMS

The two KTH programs studied in this paper are *Electrical Engineering* (‘EE’) and *Civil Engineering and Urban Management* (‘CE’). They are both 3+2-year bachelor+master programs, but quite different in structure and sustainability integration, making them interesting to compare. In this study, we are mainly focusing on the first three years, i.e., the bachelor parts of the programs.

The EE program

The EE program aims to provide students abilities to work with and develop new products within the broad area of electrical engineering, including sub-areas such as electric power engineering, information and communications technology, and machine learning. The program underwent a major revision in 2013, to re-introduce a progression of engineering skills to supplement what had become an increasingly academic education (Björn et al 2023). A previously introduced project course (EH1010) in the first year was here complemented by yet another project course (EN1020) in the second year, and by reworking the third-year bachelor thesis project (EF112X). In addition, a program integrating course (EH1110) spanning over the first three years was added, and some subject-specific courses in electrical engineering were moved to the first year to increase program cohesion. To a considerable extent, the reworked program structure was guided by the CDIO principles. In the first year, students take introductory courses in analog and digital electronics and programming in parallel with the introductory math courses. The first-year project course integrates this knowledge and introduces the students to project management in a project where they are building a robot that includes physical and software components. In the second year, students take courses in electrophysical and signals and systems, and the second-year project course requires integration of this knowledge, now with significantly more challenging technical requirements. The bachelor thesis projects in the third year are based on proposals from all faculty involved in the program and span the full set of sub-areas of electrical engineering.

The CE program

The CE program aims to provide students with prerequisites and the abilities to participate in and manage work on how buildings, infrastructure, and cities should be designed, built, and administered. The first two years mainly contains compulsory courses in mathematics and natural science subjects and civil engineering and urban management fundamentals. In year 3, students are given the opportunity to prepare for continuing studies in one of five MSc programs by creating a distinct profile toward one of five specific specializations: civil and architectural engineering, construction project management, ground and water engineering, town and traffic planning, geographical IT and real estate economics, and real estate law. The professional profile of the program is highlighted early during the first term through the course AI1527 Introduction to the Planning and Building Process, which also provides an extensive introduction to sustainability as discussed further below. Several of the other courses also contain practical and realistic exercises, seminars, laboratory work, field exercises, and project assignments, to support the students in developing engineering skills. Thus, the program provides both breadth and depth, meaning that the students get a holistic view and learn to put things in context and deal with complex issues. However, in contrast to the EE program, the program does not contain any large projects except from the bachelor thesis project.

SUSTAINABILITY IN THE TWO PROGRAMS

As mentioned, the SD Standard has earlier been operationalized and applied in an institution-wide program evaluation at the KTH Royal Institute of Technology (Rosén et al 2021, Hermansson & Rosén 2021). Starting with a pilot with ten programs, the SD Standard *rubrics* were elaborated and slightly modified to better capture essential differences in how sustainability is being integrated in programs. The modified rubrics were then used in the institution-wide evaluation. To facilitate evaluation in relation to the rubric levels, a set of indicators (i-v) were introduced which are here reproduced in Table 1. The sustainability status in the EE and CE programs were, as seen in the table, rated to correspond to SD Standard rubric levels 1 and 3 respectively. The rational for these ratings will here be discussed in relation to the indicators i-v.

Table 1: Evaluation outcomes for the two programs. (Reproduced from Rosén et al. 2021 where the EE program was labelled ‘E’, the CE program was labelled ‘B’, and ‘SD’ is used as an abbreviation for Sustainable Development).

Indicator Program	EE	CE
i) Program objectives (0-3)	1	2
ii) Introduction to SD at an early stage of the program (0-2)	1	2
iii) Number of compulsory courses with *minor* SD learning experiences	1	4
iv) Number of compulsory courses with *substantial* SD learning experiences that are developing students' *knowledge* for SD	0	1
v) Number of compulsory courses with *substantial* SD learning experiences that are developing students' *knowledge* & *skills* for SD	0	1
SD standard rubric level (0-5)	1	3

Program Objectives (indicator i)

The Swedish Higher Education Ordinance stipulates overarching learning objectives for all Swedish university degrees. For the Master of Science in Engineering degree, which the CE and EE programs lead to, there are twelve such national overarching goals. Three of these are related to sustainability and are here reproduced in Box 3. As seen, the first captures the very essence of engineering *skills*, whereas the second and third can be seen as concerning *attitudes*. Hence, neither sustainability *knowledge* nor *key competencies for sustainability* are explicitly considered in these goals, which hereby can be seen as somewhat weaker than the SD Standard (Box 1 & 2). In line with these observations, the first indicator (i) in Table 1 indicates that sustainability-related program objectives are either: missing (i=0); some (i=1); in line with the Swedish Higher Education Ordinance in Box 3 (i=2); or more extensive/ambitious (i=3).

Box 3: Sustainability-related degree requirements for the Master of Science in Engineering degree (*civilingenjörsexamen*), as stipulated in the Swedish Higher Education Ordinance.

- Ability to design and develop products, processes and systems with consideration of human prerequisites and needs and the society's goals for economically, socially and ecologically sustainable development.
- Ability to formulate judgements considering relevant scientific, societal and ethical aspects, and demonstrate an awareness of ethical aspects of research and development work.
- Insight into the possibilities and limitations of technology, its role in society and the responsibility of humans for its use, including social, economic as well as environmental and work environment aspects.

The EE program

The subset of the EE program objectives that could be related to sustainability are here reproduced in Box 4. As seen, there are no explicit considerations of sustainability or sustainable development. However, the first three objectives concern *environment*, *society*, economy (*business*), and related responsibilities and impacts, and the fourth concerns *systems perspectives*, *holistic viewpoint*, and *lifecycle*. Sustainability can hence be seen as implicitly considered by these objectives; however, this relies on how these objectives are enacted in the program and what meaning is given to *insight*, *consideration*, *understanding*, and *respect* in the students' learning and assessment. As seen in Table 1, the EE program objectives were in Rosén et al. (2021) rated as i=1, i.e., weaker than the Swedish national goals. While it is the view of the program director that the program does indeed fulfill these national requirements, it is also clear that the entirety of the learning objectives is not accurately reflected in the program objectives, so the rating is deserved. In particular, the program objectives do not reflect the "*ability to design and develop products, processes, and systems with consideration of human prerequisites and needs and the society's goals for economically, socially and ecologically sustainable development*", which need to be rectified in upcoming revisions of the program objectives. This objective is to quite some extent already addressed by the progression of project courses. How to enact it more deeply with regards to sustainability, is elaborated in following sections.

Box 4: The subset of the EE program objectives that can be seen as related to sustainability.

- Exhibit the insight that problem-solving takes its point of departure in needs and functionality, with consideration to business conditions, environment, and society.
- Exhibit insight into the possibilities and limitations of technology, its role in society, and the responsibility of humanity for how it is used nationally and internationally.
- Exhibit an understanding of and respect for the significance of how electrical engineering affects people, society in general, and the environment with respect to limited natural resources.
- Be able to analyse electrical engineering problems through a systems perspective, with a holistic viewpoint of technical systems and their life cycles, from the idea and needs to specifications, development, manufacturing, operation and decommissioning processes.

The CE program

The subset of the CE program objectives that can be seen as related to sustainability are here reproduced in Box 5. This program has used the national goals as basis for formulating the program objectives. Hereby, the first two objectives in Box 5 closely resembles the first and third national goals in Box 3, but further specified with regards to civil engineering. The second national goal (Box 3) is however not considered, but since a third *knowledge* related program objective has been added, the third in Box 5, the program objectives were in Rosén et al. (2021) rated as i=2.

Box 5: The subset of the CE program objectives that can be seen as related to sustainability.

- Demonstrate the ability to develop products, processes and systems within the technological area of Civil Engineering and Urban Management, taking into account the conditions and needs of human beings and society's goals for economic, social and ecological sustainable development.
- Demonstrate insight into the opportunities and limitations of urban management, its role in society and the responsibility of human beings for how it is used, including ethical, social, financial as well as environmental and work environment aspects.
- Demonstrate understanding of the significance of technology applications for sustainable urban development as well as how the planning, construction and administrative procedure, the built environment and physical infrastructure can be developed.

Introduction to sustainability at an early stage in the program (indicator ii)

The SD Standard emphasize that the *concepts of sustainability, potentials and limitations of science and technology and related roles and responsibilities of engineers*, should be *established at an early stage of the education* (Box 1). The second indicator (ii) in Table 1, indicates whether an introduction to sustainability at an early stage of the program is: missing (ii=0); exists (ii=1); or is extensive/ambitious (ii=2).

The EE program

In this program the students get a brief introduction to sustainability in the course EH1110 Global Impact of Electrical Engineering. This 7.5 ECTS credits course was included in the program as a program-integrating course extending through the first three years. The course includes lectures, writing of individual essays on treated topics, and discussion seminars in smaller mixed groups of 10 to 15 students moderated by a faculty member. The course broadly covers the applicability and impact of electrical engineering on society, including sustainability. Two of the ILOs address sustainability: "*review critically and reflect on the role of the electrical engineer in a sustainable society*" and "*analyze and form an opinion on the possibilities and limitations of electrical engineering and its role in society and the responsibility of people for its use, including social and economic aspects*". Hence, the focus is on sustainability *knowledge* and *attitudes*. Although not explicitly mentioned by the ILOs, environmental sustainability is frequently addressed in lectures and seminars. Assessment is through the essays and by requiring students to take an active role in the seminars. Since the moderation of the seminars and the grading of the written assignments are distributed across 30 or so faculty members, there is a challenge to maintain a uniform quality and some seminar groups might place less emphasis on sustainability.

The CE program

In this program the students get a rather thorough introduction to sustainability in the 13.5 ECTS credit course AI1527 Introduction to the Planning and Building Process, that is running over the whole first semester. It introduces and provides a basis for the whole program, for example dealing with infrastructure and planning, natural resources, sustainable infrastructure, real estate development, and building and civil engineering structures. Covered applications are linked to various aspects of sustainability. The ILOs provide a broad integrated account for various technical aspects of civil engineering and in addition to that: perspectives on human needs; historical and future perspectives on society and urban development; natural preconditions such as soil, water and ecosystem; political, legal, and administrative aspects; economic, social and ecological aspects of sustainability, including ethical, gender and equality aspects, and possible conflicting dilemmas between them; and the professional role of engineers and how they can influence the development in society. Most of the ILOs concerns sustainability *knowledge* but some are also concerning sustainability related *attitudes*. Teachers from several different departments, representing social sciences, natural sciences, and purely technical disciplines, are involved in the course.

Minor and Substantial SD Learning Experiences (indicators iii-v)

The indicators iii-v in Table 1, are simply counts of courses in the program with sustainability related ILOs and corresponding activities and assessment. Only courses that all students in the program take are considered. The evaluation hence indicates the base-line status of sustainability in the program, while some students might reach further through elective courses. These indicators make distinctions between *minor* (iii) and *substantial* (iv-v) sustainability learning experiences. What can be considered as minor and substantial is of course not absolute, but some guiding ideas are elaborated in Box 6. In accordance with the slightly modified rubrics proposed in Rosén et al (2021), distinctions are also made between courses that only concern sustainability *knowledge* (iv) and courses that also provide students opportunities to develop sustainability *skills* (v). It should be noted in Box 1 and Box 2, that the SD Standard in addition to *knowledge* and *skills* also considers sustainability *attitudes* and *key competencies*, these are however not considered by the indicators iii-v but clearly in rubric level 4. Some guiding ideas on how to interpret sustainability knowledge, skills, attitudes, and key competencies, are provided in Box 6.

Box 6: Guiding ideas of how to interpret terms in the SD standard rubric levels in Box 2.

• A *minor* sustainable development (SD) learning experience can typically be a small SD related module, and related ILOs and assessment, integrated in a core engineering course or in a program introductory course, corresponding to <1 ECTS credit.
• A *substantial* SD learning experience can for example be a course that is more or less completely dedicated to SD, or an extensive integration of SD in a core engineering course in terms of several ILOs and related learning activities and assessment, corresponding to several ECTS credits.
• Rubric level 3 (Box 2) requires substantial SD learning experiences that, in addition to developing students' SD *knowledge*, also develop students' SD *skills*, which typically can be abilities: to contextualize, operationalize, and apply SD knowledge in engineering work; to evaluate environmental, social and economic consequences; and to take action for sustainable development based on such evaluations for example in decision making and engineering design.
• Rubric level 4 (Box 2) further requires development of students' sustainability attitudes and key competencies. *Attitudes* are typically related to assumptions, norms, values and worldviews (e.g. Sterling 2011). *Key competencies for sustainability*, such as systems-thinking, critical-thinking, and abilities to communicate and collaborate across disciplinary and cultural borders, are clusters of individual dispositions comprising knowledge, skills, motives, and attitudes, that within the Education for Sustainable Development (ESD) domain are considered necessary for coping with the increasingly diverse and interconnected world and for taking action on sustainability and transformation (e.g., Wiek et al 2016, UNESCO 2017, Malmqvist et al 2022).

The EE program

In the SD Standard application in the institution-wide program evaluation in Rosén et al (2021), the only sustainability learning experience identified in the EE program, was the program-integrating course (EH1110) described in the previous subsection. As indicated in Table 1, the program was hereby observed to have only one *minor* (iii=1) and no *substantial* (iv=v=0) sustainability related learning experiences and was rated to only reach the SD Standard rubric level 1. There were however some sustainability related activities going on in the bachelor thesis course that were not considered in the evaluation, and in some other courses that had not yet been formalized in terms of ILOs and assessment and could therefore not be identified in the evaluation. These 'unnoticed' activities, and how they are being formalized and enhanced, will be described in the following section.

The CE program

As indicated in Table 1, the CE program was in Rosén et al (2021), found to have four *minor* (iii=4) and two *substantial* sustainability learning experiences, one mainly concerning sustainability *knowledge* and *attitudes* (iv=1) and the other also providing students opportunities to develop sustainability *skills* (v=1).

The substantial learning experience that concerns sustainability *knowledge* and *attitudes* is the program introductory course (AI1527), that was described in the previous section. The other substantial sustainability learning experience is the course AL1301 Natural Resources Theory. It has several ILOs that concern *knowledge* and *skills* related to *environmental science and methodologies*, as well as general and environmental aspects of sustainability, for example: "*perform calculations of materials and energy flow both within the anthropogenic and natural systems*"; "*use scientific criteria to evaluate ecological status at soil and water resources in relation to their use in society*"; "*apply basic thermodynamic principles and carry out simple energy calculations regarding renewable energy resources*"; "*draw independent conclusions about possible results following implementation of Swedish environmental objectives and the global sustainability goals*".

Among the minor sustainability learning experiences is the course AH1030 Urban Development and Transport System. Dealing with the importance of coordinating planning and traffic systems, dwellings, and green areas, in order to ensure long-term sustainable civil engineering, it supports students in developing *knowledge* as well as *skills* related to environmental, social, and economic sustainability. Another minor sustainability learning experience is the course AI1802 Project Management and BIM in the Built Environment. It considers *knowledge* related to general aspects of sustainability through the ILO: "*describe how project management and BIM can contribute to a more sustainable built environment*". Yet another course is AI1525 Legal Framework of the Built Environment, which has the overall objective that "*the student after finishing the course should know the basics of the system of law that regulates and has impact on sustainable development in the built environment"*. The fourth minor sustainability learning experience is the course AI1128 Economics of the Built Environment that concerns *knowledge* related to economic aspects of sustainability through the ILO: "*explain how economic policy instruments may be used to achieve a sustainable society*". Finally, the bachelor thesis project course, that was not included in the evaluation in Table 1, includes an ILO that concerns understanding of the meaning of a sustainable development within the subject area.

OPPORTUNITIES AND BARRIERS TO ENHANCING THE STATUS OF SUSTAINABILITY

This section describes how the status of sustainability has been enhanced in the two programs, as a reaction to and with guidance from the SD Standard application, and related opportunities and barriers are discussed.

The EE program

As described, the sustainability status in the EE program was rated as low in the institution-wide evaluation. However, there were some sustainability related activities in the program that were not identified in the evaluation. For example, the bachelor thesis course, has one sustainability-related ILO that considers the student's ability to "*show awareness of social and ethical aspects including economic, social and ecologically sustainable development*". It is addressed in a workshop where the students collaborate on writing thesis introductions that should discuss sustainability aspects of their projects. Minor SD learning experiences have also been introduced in the mandatory course EI1110 Electrical Circuit Analysis, and in the conditionally elective course IL2204 Semiconductor Devices for Integrated Circuits. Further, some aspects of social sustainability, such as ethics, diversity, and inclusion, are addressed in the first-year project course in connection to the challenges of working in project groups and when discussing the project outcomes. The second-year project course has the largest potential to integrate environmental sustainability skills, but this has not yet been realized. This said, the new ILO, "*make a design and build a product where choices are made considering sustainability*", was introduced in 2022, following the discussion that was a direct consequence of the institution-wide application of the SD Standard. Work is now going on to formalize and further enhance these sustainability related goals and activities, and to ensure progression of knowledge as well as skills related to social and environmental sustainability and ethics through the sequence of the three project courses (EH1010, EH1020, EF112X). After such development, the program could have three minor (iii=3) and two substantial (iv=1 & v=1) sustainability related learning experiences. This would make the program corresponding to the SD Standard rubric level 3, and thereby complying with KTH's new sustainability objectives for education (KTH 2021).

As may have been noticed by the reader, this paper has focused on only a handful of courses out of the 22 mandatory and 13 conditionally elective courses that constitute the first three years of the EE program. This points toward one of the most significant barriers to enhancing the status of sustainability in the program. Electrical engineering is a well-established subject internationally and this program has a very long history, starting with the introduction of electrical engineering as a subject at KTH in 1901. This carries strong expectations of what the curriculum should contain. As the bachelor+master is now organized, there are requirements on the first three years to cover a broad range of electrical engineering theory to qualify the students for nine different master programs in sub-disciplines spanning from machine learning to electrical power engineering. This leaves limited room for more comprehensive sustainability integration. Further, research in electrical engineering at KTH is strong, with a QS ranking by subject in the range of 16 to 25 worldwide, which is the highest of all subject areas at KTH. This goes hand in hand with a strong-minded faculty sometimes protective of their respective sub-topics. The question of reducing any electrical engineering sub-topic to allow more extensive sustainability integration is still sensitive. Similar resistance was evident when the project courses where introduced.

The CE program

For the CE program, the outcome from the SD Standard application in the institution-wide evaluation, became a positive injection to continue the work on further enhancing the status of sustainability that has been going on more or less systematically since 2013. Even though the program is already corresponding to the SD Standard rubric level 3, and thereby comply with KTH's new sustainability objectives for education (KTH 2021), the program management is determined to continue leading the way. A new deeper evaluation has been initiated, through close dialogue and collaboration between the director of the CE program (second author of this paper), directors of two of the connecting master programs, and an engaged expert from the KTH Department of Learning (first author of this paper). This has included several meetings and workshops with teachers and program advisory boards that also include students. Progressing the program beyond rubric level 3 would for example require enhanced opportunities for transformative learning and development of students' key competencies for sustainability. One possibility that is considered could be to redesign the existing program introductory course (AI1527), by including a larger project where the students should work with real world wicked problems related to sustainable urban or rural development. Such learning could be further progressed by establishing yet another challenge-driven project course in year two or three. However, similarly as for the EE program, such more extensive modifications would most probably meet resistance by faculty members who are concerned about maintaining 'their own' sub-topics and courses in the curriculum.

Discussion

As indicated in Table 2, the SD Standard rubric levels can be mapped to the different response levels, or strategies, to sustainability in education that are outlined and discussed by Sterling (2004) and Kolmos et al (2016). Based on this it can be argued that the EE program has earlier applied an add-on strategy but is now, as a reaction to the SD Standard application in the institution-wide evaluation, working towards an integration strategy. The CE program has already established an integration strategy but is now considering some re-building, and possibly more extensive transformations, to enable progression beyond SD Standard rubric level 3.

Table 2: The SD Standard rubric levels mapped to the different response levels/strategies to sustainability in education according to Sterling (2004) and Kolmos et al (2016).

Response levels/strategies (Sterling 2004, Kolmos et al 2016)		**SD Standard rubric levels**
Denial or Rejection	no change	0
Add-on	weak, education about sustainability	1-2
Integration	strong, education for sustainability	3-4
Re-building or Transformation	very strong, sustainable education	4-5

Electrical engineering and civil engineering share similarities in being old and well-established academic disciplines and professions. With this comes the burdens of strong traditions and expectations from society, industry, and senior faculty, for example on what the curricula should contain. Further, there might be economic and career incentives that make faculty protective of their sub-disciplines, competence areas, and courses. Such factors can create significant barriers to change, in particularly against more extensive integration of sustainability since this will not only require interdisciplinary perspectives and new teaching and learning approaches, but it could also question the techno-centered and reductionistic foundations of traditional engineering science and education. One explanation for the difference in sustainability status between the CE and EE programs, is that civil engineering as a discipline incorporates technology as well as societal, social, economic, and ecological, perspectives, while electrical engineering is more techno centered. Another significant factor is the presence of individual enthusiasts or groups among faculty, who have interest, competence, and courage, to drive change. For example, within the environment surrounding the CE program at KTH there are several such individuals and research groups that drive change with regards to sustainability. Similarly, the establishment of the project courses in the EE program was driven by individuals and a research group engaged in project management at the electrical engineering department. This highlights the potential for mutual learning in collaborations across disciplines and between programs, where for example, in the case of this paper, the EE program could benefit from finding inspiration and support from the CE program in enhancing the status of sustainability, while the CE program could find inspiration and support from the EE program in developing project courses. This also highlights the importance of concerned and competent leadership and top-down support, on the program level, as well as on the department and the university levels.

CONCLUDING REMARKS

The paper has shared deeper insights from application of the SD Standard and discussed related opportunities and barriers. The study is limited in only concerning two programs in the same national and university contexts. However, since the two studied programs are quite different in disciplines, structures, and levels of and approaches to sustainability integration, the study is contributing with specific as well as general perspectives that could be valuable also beyond the studied context. The study confirms the conclusions from Rosén et al (2021), that the SD standard is useful, not only for guiding and evaluating program development towards full implementation of the SD Standard, but also for evaluating and enhancing the status of sustainability in basically any engineering program, independently of status and conditions. The SD standard provides a framework and terminology for dialogue and collaboration, within as well as between programs, that can be used for driving change from an add-on approach, through integration approaches, toward more extensive transformations.

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II CDIO Implementation

DEVELOPING A DIDACTIC FOUNDATION FOR THE TECH FACULTY AT AARHUS UNIVERSITY

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ABSTRACT

In January 2022 the Faculty of Technical Sciences (TECH) at Aarhus University (AU) appointed a working group to develop a *didactic foundation* for teaching at TECH. The background was a need to develop a joint platform for teaching, pedagogical competence development, and other educational activities at the faculty, after a recent history of organizational mergers and changes, and subsequent development of a new joint strategy. The working group was to identify important factors that should characterize future teaching at TECH and propose a commonly recommended foundation upon which TECH teachers can collectively build, reflect, and improve their teaching. This paper will justify and describe the work process, present and reflect upon the outcome, relate the outcome to the CDIO Standards and Syllabus, discuss lessons learnt, and provide advice for others engaging in similar work.

KEYWORDS

Didactics, Pedagogy, Change Management, Teaching Practice, Faculty Competence,
Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12

INTRODUCTION AND BACKGROUND

In 2010 the Engineering School of Aarhus was merged with Aarhus University. The Engineering school was a university college educating professional bachelors (Ministerial order, 2013), and solely focused on teaching. Before 2010, Aarhus University and the Engineering School of Aarhus jointly had a master's program in technical IT; a programme that started in 2004 (Aarhus University, 2004). After the merger in 2010, one department (the Dept. of Engineering) and one school (the Aarhus School of Engineering) were formed. These two entities drifted further and further apart, so in 2021 the Department of Engineering and the School of Engineering were dissolved and four discipline-based departments were formed: the Department of Biological and Chemical Engineering, Department of Civil and Architectural Engineering, Department of Electrical and Computer Engineering, and Department of Mechanical and Production Engineering. These four departments make up the TECH faculty, bringing together a quite diverse set of study programme types, teaching cultures, disciplines and thematic areas under common leadership. A strategy process was initiated and a new joint strategy was ready a year after the organizational change (The TECH Faculty, 2022).

The CDIO framework has been a foundation for the professional bachelor programmes since the Aarhus Engineering School joined the CDIO community in 2010. The CDIO principles were therefore, by many, seen as "the way to teach practice-based engineering". However, especially within the former Department of Engineering, there was resistance towards CDIO. The faculty leadership, therefore, saw a need to develop a joint platform for teaching, pedagogical competence development, and other educational activities at the faculty, rather than just adapting CDIO as a basis for all programmes.

In January 2022 the vice dean of education at AU's Faculty of Technical Sciences (TECH) therefore appointed a working group to develop a *didactic foundation* for the faculty. The group consisted of particularly engaged Directors of Studies, a Head of Programme, professors and associate professors with teaching duties, and a student – in all representing TECH's diversity of organizational sections, study program types, teaching cultures, and disciplines. The group was supplemented by an international guest researcher with experience in strategic change processes in STEM education (Øien & Bodsberg, 2022; Øien et al., 2022). It was given the tentative mandate to identify important factors that should characterize future teaching at TECH - and propose a commonly recommended foundation upon which TECH teachers may collectively build, reflect, and improve their teaching. The starting point of the work was '*Which values should our teaching be built upon?*' The stated goal was to develop something which could be seen as practically useful by the organization, and which over time would stimulate reflections, conversations, culture and competence building related to educational activities.

RELATED WORK

D'Andrea and Gosling (2005) note in their introduction (p. 7):

It seems that every higher education institution wants to boast that it offers 'high quality learning and teaching'. Mission statements consistently claim that universities and colleges seek to provide excellent teaching and a high quality learning environment. But it is less than obvious that institutions are either clear about what these goals mean or actually pursuing these goalswith strategic vision. In most cases neither of these key goals is well defined: what is excellent teaching and what constitutes a high quality learning environment? And the manner in which institutions are attempting to achieve these goals is many and varied. Often the approach simply reflects the historical traditions of a particular institution and its associated values and practices.

The present work can be seen in this light: As an attempt to gather and formulate elements that constitute and support excellent teaching and a high-quality learning environment.

According to Gedda et al. (2016), *Luleå University of Technology* developed what was called "The Pedagogical Idea". It was a *common pedagogical idea, communicating core values of teaching and learning for the whole university (including e.g. healthcare, art and teacher education).-* (p.306). It was developed after a not-so-successful development process leading to what they called *The Creative University,* including the concepts of Knowledge Building and Arena. According to the authors, the Creative University was a top-down process, creating resistance among the teachers. As they note, however, *the handover to the teachers who were expected to implement it in a teaching context was weak. As the concept was based on* *principles of student-centred learning, it made high demands on educational knowledge and teaching skills among the university professionals."* (p. 305).

This indicates that when formulating guidelines and advice that are to be practically useful for university teachers, it is important to combine a top-down approach with bottom-up user involvement and to emphasize a practical, user-oriented approach, rather than a theoretical, research-oriented framework. Note that this does *not* imply that the guidelines and advice should not be based on sound research-based knowledge – it simply indicates that the formulations and wordings eventually presented to the target audience should be simple, context-specific and practically oriented, rather than heavily relying on scientific terms from educational development research and pedagogical theory.

The standards of the CDIO initiative (CDIO, 2023) can also be seen as a framework describing what is needed to enable and implement good teaching. It has previously been used at Aarhus University to initiate discussions about teaching, but in many cases, teachers found it to be abstract and too much focused on organizational matters. As an example, many teachers from the professional bachelor see e.g. standard 1 ("*A CDIO program is based on the principle that product, process, system, and service lifecycle development and deployment are the context for engineering education. Conceiving–Designing–Implementing–Operating is a model of the entire product, process, system, and service lifecycle. The Conceive stage includes defining customer and societal needs; considering technology, enterprise strategy, and regulations; and, developing conceptual, technical, and business plans. The Design stage focuses on designing a solution to the addressed need, that is, the plans, drawings, and algorithms that describe what will be implemented. The Implement stage refers to the transformation of the design into the product, process, system, or service, including manufacturing, coding, testing and validation. The final stage, Operate, uses the implemented product, process, system or service to deliver the intended value, including maintaining, evolving, recycling and retiring. The consideration of environmental, social, and economic sustainability is an integral part throughout the lifecycle*." (CDIO, 2023)) as stating the obvious. They have a background in practise, the students have an internship as an important and integral part of their studies (where the teachers serve as a link between the institution and the company), use Insights Discovery (A psychometric tool based on the psychology of Carl Jung, see (Insights, 2023)) and many more activities directed towards becoming "an engineer who can engineer".

PROCESS AND TIMELINE

During its 11-month working period, the working group held several meetings, commencing with a discussion on the working group members' individual experiences and perspectives on what constitutes great teaching. It was quickly agreed, however, that including international perspectives, and taking into account a knowledge-based approach to educational development, would enhance the quality of both discussions and content.

Subsequently, the focus was therefore shifted to identifying how other institutions internationally have explicated a didactic foundation for teaching and learning. For this purpose, educational strategies and pedagogical principles from several relevant universities abroad were surveyed (Luleå University of Technology (2023), NTNU (2018), DTU (2023), KTH (2012) TU Delft (no reference), Chalmers (no reference)). Perspectives from these were also reviewed against AU's and TECH's strategies. The following education-related key objectives from the AU strategy were particularly noted as important to comply with:

- *Engaging in teaching and learning*

- *Strengthening students' general competencies*
- *A future-proofed graduate competency profile*
- *More career-oriented elements in the degree programmes*

In the TECH strategy, it was noted that an important focal point is to '*accommodate all our students and meet them where they are. Our programmes and teaching must involve and activate students and support their academic and personal development in the direction they have chosen to take.'* Other education- and student-related goals in the TECH strategy relevant to the working group's mandate include

- *Meet our students where they are and support their academic and personal development*
- *Provide students with space and opportunity to engage in, and contribute to, solving major societal challenges in collaboration with other knowledge fields*
- *Facilitate in-depth academic qualifications and capabilities*
- *Foster a common culture for how we design education that supports these goals.*

International principles and practices broadly accepted as state-of-the-art were also mapped, most notably the CDIO Standards (The CDIO Initiative website, 2022). Relevant findings from the surveys and mappings were extracted and reformulated to fit the local context and use.

It quickly became clear during this phase that the scope of the group's mandate neither could nor should be limited only to course-level teaching practices: The students' role, not to mention study programme perspectives, must also be considered. To clarify the *students*' roles, expectations and needs, groups of students from selected programmes were therefore invited to several workshops. Initially, the students were invited both to give their views on good teaching and the state of today's education, and to describe their wishes for concrete improvement. One important finding from these student workshops was that students' perception of quality is heavily influenced not only by teaching practices and curriculum design but also by the *infrastructure, facilities and practical framework conditions* under which teaching takes place. It was therefore decided to broaden the working group's scope to also include advice to the faculty on *institutional framework conditions.* It may perhaps be argued that this broadening of scope stretches the term 'didactical foundation' quite far, but since this term had been used from the start it was decided to continue using it for the process outcome.

The students' additions and modifications to the draft didactic foundation were subsequently used as one of the starting points for discussion in a subsequent *Head of Programme* workshop. The main focus of this workshop was on discussing, from a study programme perspective, the current strengths and weaknesses of TECH's education portfolio, desired future development, and programme design principles. Subsequently, to ensure that individual teachers' and course responsibles' perspectives, views and concerns were properly included in the process, all *academic staff* at TECH were invited to participate in a questionnaire, giving their responses to the following questions:

1) Which aspect of your teaching is most important for you to maintain in the future?
2) If you were to change one thing about your teaching, what would that be?
3) Name one thing that you believe students should do to contribute to their learning.

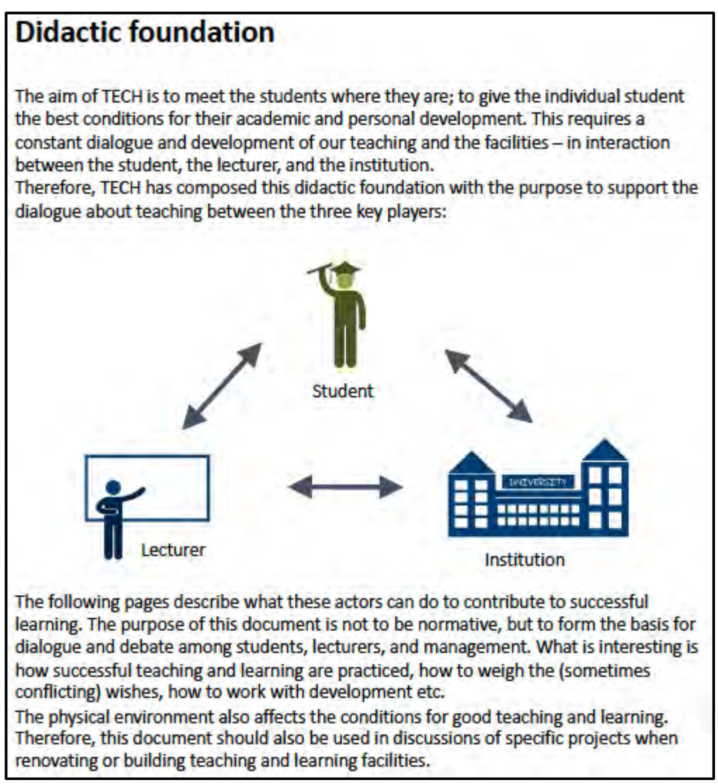
Responses from the questionnaire, which had a response rate of more than 25%, were subsequently analyzed by the working group, and thereafter discussed with student representatives. A second workshop was also held with those teachers who had signaled in their questionnaire responses that they were interested in giving further input to the process. The analysis of responses showed that time for, dialogue with, and activation of their students were in general high on the teachers' agenda. The need for variation in teaching methods and learning activities, coupling of theory to practice, and improvement of institutional framework conditions, including more time for development and improvement of their teaching, were also mentioned by many. The importance of students' engagement, steady work, curiosity, independence, critical thinking ability, and responsibility for their learning was also highlighted.

Finally, meetings were held with the NAT-TECH Study Administration and the NAT-TECH Building Services, to get input in particular on the part of the foundation document dealing with *institutional responsibility* in the collective work towards better teaching and learning and, ultimately, improved educational quality. Finally, the faculty management were invited to comment upon the overall results before the group's deliverable was finalized.

Throughout the whole process, a draft of the deliverable document had been maintained, discussed in the working group, and iteratively refined and improved as new perspectives, responses, findings and insights as described above were continuously added. The final deliverable was submitted to the TECH management in December; its contents are detailed in the next section. The deliverable is a concise 4-page document, describing in succinct and concrete bullet points important expectations, principles, guidelines and recommendations that respectively students, lecturers, and the institution (in particular faculty management and administration) should heed to *collectively* contribute to excellent education quality.

RESULTS AND LINKS TO THE CDIO FRAMEWORK

The front page of the final deliverable document, as presented to the target audience, is shown in Figure 1. It briefly describes the context and strategic motivation for the work and also provides some pointers on the intended use of the document.


Didactic foundation

The aim of TECH is to meet the students where they are; to give the individual student the best conditions for their academic and personal development. This requires a constant dialogue and development of our teaching and the facilities – in interaction between the student, the lecturer, and the institution.
Therefore, TECH has composed this didactic foundation with the purpose to support the dialogue about teaching between the three key players:

The following pages describe what these actors can do to contribute to successful learning. The purpose of this document is not to be normative, but to form the basis for dialogue and debate among students, lecturers, and management. What is interesting is how successful teaching and learning are practiced, how to weigh the (sometimes conflicting) wishes, how to work with development etc.
The physical environment also affects the conditions for good teaching and learning. Therefore, this document should also be used in discussions of specific projects when renovating or building teaching and learning facilities.

Figure 1. Front page of the final delivered document

In Tables 1 – 3, the first two (leftmost) columns list all the bullet-point format recommendations that follow on the subsequent pages of the deliverable document, for respective students, teachers, and the institution. In the third (rightmost) column, we have indicated (for each bullet point listed in the foundation document) which CDIO Standards and/or areas in the CDIO Syllabus we believe it most strongly supports, relates to, depends on, or is relevant for (if at all). As stated earlier, although the foundation document as a whole is in principle independent of any particular didactical 'school of thought', the CDIO principles as reflected through the Standards and the Syllabus have been one important inspiration, and a reference for excellent international practice, throughout (The CDIO Initiative website, 2022).

The working group also believe – as illustrated by the rightmost column in Tables 1-3 - that the document's recommendations as a whole comply with, are supportive and enabling of, and in some cases rest on CDIO principles. Thus the recommendations may help develop *good practice* in line with both the CDIO Standards and the CDIO Syllabus. In some cases, they may also serve as *motivation* for development in line with CDIO Standards, e.g., when it comes to developing engineering learning spaces or faculty competence development programmes.

However, it will be seen that the CDIO standards or syllabus are *not explicitly referred to* in the foundation document, and neither are the recommendations designed to ensure full CDIO compliance *as a goal in itself*. The development process uncovered that the CDIO concepts as formulated in the standards and syllabus are not necessarily easy to grasp or operationalize for individual teachers and students without a background in educational development or strategy. Central CDIO principles turn out to be more easily understood - and thus probably easier to convert into practice - if reformulated into simpler wordings that are adapted to the specific local context, language, culture, and target audience.

Also, this work has dimensions that go beyond the scope of the CDIO standards and syllabus, as it also pinpoints a number of practical and cultural aspects linked to physical framework conditions and human behaviour. Some of these aspects (marked with '-' in Tables 1 – 3) deal with practical issues related to well-being, health, safety, human relations, individual mindsets, and psychosocial learning environments. However, we argue that resolving such issues are important, sometimes necessary (but of course not sufficient), conditions for efficiently enabling practical implementation of CDIO principles. Thus we believe that the foundation document can be used both to 'prepare the ground' for CDIO implementation as well as providing useful guidelines for how to do such implementation in practice - if that is the goal.

Table 1. Recommendations for students, with links to the CDIO Standard and Syllabus.

The student …		**Related CDIO Standard(s) and/or Syllabus areas**
Engages in own learning	*Participates actively: Asks about what is not understood, discusses with the teacher and fellow students, seeks out knowledge, seeks feedback*	Standards 8, 11 and Syllabus 2.4
	Prepares according to the expectations	Standard 8
	Assesses which learning resources best support own learning – both physical and digital	Standard 8, Syllabus 2.4
	Is curious – preferably also outside materials	Standard 8
Establishes good conditions for own learning	*Reflects on own learning*	Standards 8, 11
	Accepts that learning requires a (large) effort	Standard 8 Syllabus 2.4
	Prioritizes own time, including prioritization between work, leisure and studies	-
	Is open to opportunities (student jobs, research, ...)	-
	Shows up well-rested	(Syllabus 3.1)

Contributes to a good learning environment	*Respects fellow students and contribute to a professional environment*	Syllabus 3.1
	Contributes to a good social environment	Standard 6 Syllabus 3.1
	Contributes to a safe environment	Standard 6
	Collaborates with fellow students	Standards 6, 8, Syllabus 2.4 and 3.1
	Contributes to systematic quality assurance work, for example by answering evaluations	Standard 12

Table 2. Recommendations for teachers, with links to the CDIO Standard and Syllabus.

The lecturer …		**Related CDIO Standard(s) and/or Syllabus areas**
Has an eye for the student(s)	*Shows respect for the student*	-
	Shows an interest in the student	-
	Challenges the student	Standard 8
	Believes in the student's potential to develop	-
	Keeps her/his agreements with the students	-
	Is available and spends time with the students	-
	Differentiates the teaching so that it is based on the student's competences	Standard 8
Creates an inspiring learning environment	*Provides specific, well-founded, focused, forward-looking, and timely feedback*	Standard 11. Syllabus 3.1
	Creates commitment in the teaching situation	Standard 6
	Has an active stance on the form of instruction that provides the best learning	Standards 7, 8
	Stimulates dialogue/interaction in the important physical teaching	Standard 8
	Avoids monotony by varying the teaching methods	Standards 5, 7, 8, 9, 10
	Make good use of digital possibilities	Standard 6
	Deliberately integrates personal, interpersonal and professional competencies	Standard 7
	Supports learning in communities (group work, project work)	Standard 6, Syllabus 3
	Supports a culture characterized by "no stupid question" and "acceptance of errors"	Standards 8, 11
	Ensures freedom of choice for the students, for example in relation to project assignments, learning resources, open assignments, ...	-
	Aligns teaching, exams, and learning activities to learning outcome, and discusses these with the students	Standards 2, 7, 8, 11
	Awareness of the balance between practical elements and theoretical elements	Standards 5, 7, 8 Syllabus 4
	Awareness of the balance between types of teaching activities (lecture, lab work, problem solving, ...)	Standards 6, 8
Demonstrates high subject knowledge	*Keeps the teaching content relevant in relation to the employers' needs, as well as to development and research within the area*	Standards 1, 2. Syllabus 1.1 – 1.3 + 2.1 - 2.3 + 4.2
	Motivates her/his course, puts it into context	Standards 1, 4. Syllabus 1.4 + 2.1 – 2.3 + 4
	Creates a link between practical and theoretical elements	Standards 3, 4, 5, 7, 8 Syllabus 4

Ensures coherence with other disciplines and society	*Ensures a common thread within the semester and across semesters by having knowledge of and providing explicit references to other elements of the study programme*	Standards 2, 3
	Ensures awareness of the societal relevance of the programme	Standards 1, 2 + Syllabus 1.4, 2.3, 4.1 – 4.3
	Coordinates with other lecturers in relation to deadlines, etc.	-
	Ensures progression in the study programme	Standard 3
	The actual workload of the course corresponds to the formal scope	Standard 12

Table 3. Recommendations for the institution, with links to the CDIO Standard and Syllabus.

The institution …		**Related CDIO Standard(s) and/or Syllabus areas**
Ensures good educational facilities and physical surroundings	*Ensures good indoor climate, cleanliness, power, well-functioning AV equipment, well-functioning tables and chairs*	Standard 9
	Ensures good workshops and laboratories for practical work	Standards 5, 9
	Makes study spaces and group rooms available to students (where possible, 24/7)	-
	Ensures well-functioning digital learning tools	Standard 9
	Ensures areas of identity for students on the same study programme	Standard 6
	Ensures (universal) availability	Standard 6
	Ensures good opportunities for food etc.	-
	Ensures good physical infrastructure	Standard 6, 9
	Ensures exams spread out over the exam period	-
Ensures optimal planning	*Ensures that the teaching schedule is available quickly*	-
	Ensures that planning involves the wishes of lecturers and students	-
	Ensures that it is possible for the student to create a schedule without conflicts	-
	Ensures the necessary number of teaching hours per student	-
Facilitates co-operation between relevant stakeholders	*Facilitates co-operation between lecturers*	Standard 3
	Facilitates co-operation between lecturers and administration	Standards 3, 12
	Facilitates co-operation between lecturers and heads of programmes	Standards 1, 2, 3, 12
Ensures opportunities for upgrading of qualifications and competency development	*Ensures forums for discussions about teaching*	Standards 10, 11
	Ensures ongoing competency development within didactics and other fields based on the individual's wishes and needs	Standards 10, 11

In Tables 1 - 3, all 12 CDIO standards are addressed. Naturally, some standards are represented more than others, e.g., standard 8 (active learning) is very dominant in the "Student" and "Lecturer" recommendations.

PLANS FOR FUTURE USE OF THE RESULTS

The document was, as noted previously, delivered at the end of 2022. It was very well received by the faculty management, but the obvious question is: "How will it be used"? How will the faculty members see the document? In January 2023, a workshop in one of the departments was held using the document as a starting point for discussion. Feedback from the workshop is still to be analysed. At the faculty, an "educational day" is to be implemented at each department. There are plans to use the didactical foundation as a point of departure for discussion and sharing of good practice.

SUMMARY, REFLECTIONS AND TAKEAWAY MESSAGES

We have developed a joint didactical foundation document for The Faculty of Technical Sciences at Aarhus University. Taking the existing strategic objectives of the university and faculty as a starting point, and anchoring the work in international state-of-the-art practices and principles, we have followed an inclusive, iterative working process and a 'whole-institution approach' involving all university-internal stakeholder perspectives – teachers, students, programme directors, and institutional framework condition providers. Literature studies, stakeholder workshops and interviews, multi-stakeholder discussions, and questionnaires have all given significant input to the discussions and the final results.

Among the most important take-away messages and lessons learnt along the way are:

- The quality, understanding, anchoring and usefulness of a work such as this benefit greatly from an iterative 'top-down-meets-bottom-up' refinement process based on input from multiple stakeholder perspectives, paving the way for a subsequent collective interaction towards improved educational quality.
- To ensure both quality and usefulness it is important to actively anchor recommendations and advice in research-based knowledge and international state-of-the-art principles, but at the same time take care to formulate the message in a simple, context-adapted, practice-oriented way which is suited to the target audience's needs and background.
- Expectations and advice to teachers should not be separated from expectations and advice to students, or the institution's support and facilitation: All these stakeholders should be stimulated to efficiently interact and make a *collective* effort to improve educational quality, ensuring a 'whole institution approach' (D'Andrea & Gosling, 2005).
- The viewpoints of teachers and students wrt. good teaching practices and student behaviour which facilitates learning are quite similar – and mostly also in line with international state-of-the-art knowledge on learning, as well as compliant with basic CDIO principles (Crawley et al., 2014).
- Bottlenecks hindering improved practices are arguably more related to resource limitations than to any lack of motivation for change among teachers and students or at the institutional level.

It is the working group's hope and belief that the process described in this paper has created a useful and living document which will stimulate more and better discussions about and interactions centred around teaching, learning and educational quality at the faculty. We also hope and expect the foundation document to evolve due to reflections, conversations, culture and competence-building inspired by this first version. Finally, we hope that our takeaway messages and lessons learnt may be of use as advice to others engaging in similar work.

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BIOGRAPHICAL INFORMATION

Geir Egil Dahle Øien (b. 1965) holds an MscEE degree in Electronics Engineering (1989) and a PhD degree in Telecommunications (1993), both from The Norwegian Institute of Technology. He became professor at NTNU in 2001 and served as Dean 2009-2019. He was project manager of the NTNU project 'Technology Education of the Future' 2019-2021, and an invited guest researcher at Aarhus University in 2022. Geir has extensive experience from national audits of Nordic education institutions and leads *the Portfolio Board for Enabling Technologies* in The Research Council of Norway. He has published more than 150 articles in refereed international journals and conference proceedings and has a (Scopus) h-index of 22.

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REFLECTIONS ABOUT REFLECTIONS

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ABSTRACT

A case study of the use of reflections within the Applied physics and electrical engineering program at Linköping University is presented. Reflections have been used for several years and they are done at four stages in the program, in terms of reflections at the end of the Introductory course in year one, design-implement experiences in year three and five, and a reflection document that is the last component of the Master's thesis. In the first three stages a project model is used to support the planning and execution of the project, and in the project model the project work ends with a reflection. In the reflection document connected to the Master's thesis the student reflects upon both the thesis work itself and the entire education program, according to the sections and subsections of the CDIO Syllabus. The paper describes how the reflections are integrated in the program. Experiences from student perspective are collected in a small-scale study via interviews with students from year one and year five.

KEYWORDS

Reflection, learning, project model, CDIO Syllabus, Standards: 2, 4, 5, 11

INTRODUCTION AND AIM

Reflections for learning is a wide field, and the literature in the field is comprehensive. The aim of this paper is not to give a complete overview of the area, but to present a case study of how reflection is a natural part in project-based learning. In the literature the work in Kolb (1984) about experiential learning and Kolb's learning cycle as a key reference. The learning cycle consists of the stages (i) Concrete experience, (ii) Reflective Observation, (iii) Abstract Conceptualization, and (iv) Active Experimentation. See also Gibbs and Habeshaw (1989). Within the CDIO community there are several references where reflections in different forms have been studied, where Junaid et al. (2018) and Cosgrove and O'Reilly (2019) are two examples. In addition, Cheah (2022) presents an excellent overview of the field with an extensive list of references related to reflections. Also, in project-based activities reflection at the end of the project is a standard last step. See, for example, Andersen and Schwenke (1998) and Lööw (1999).

The aim of the paper is to present a case study of the use reflections throughout the engineering education program Applied physics and electrical engineering at Linköping University. Reflections have been used for several years in four stages of the program. The first reflection is done at the end of the Introductory course (see CDIO Standard 4) that is given during the fall semester of the first year of the program. Reflections two and three are included in the design-build experiences (see CDIO Standard 5) in year three and year five. In these three cases the reflection is based on the reflection document that is part of the LIPS (Swe: Lätt Interaktiv ProjektStyrningsmodell) project model. Finally, the fourth stage is the reflection document that is a mandatory part of the Master's thesis at the end of the education program. The reflections are mainly done in connection with project-based learning activities, which can be seen as a limitation, but, on the other hand, it comes in very naturally in such a learning activity. In addition to presenting the case study, the aim is also to present a small-scale study of how the reflections are seen by the students.

The paper starts with a background section including a short overview of the CDIO framework The following section focuses on how the framework has been implemented within Linköping University and the Applied physics and electrical engineering program, with emphasis on how reflections are used at several stages in the program. In the next section some outcomes of interviews and surveys with students in year one and year five are presented, and the next section contains summary and some conclusions.

BACKGROUND

The CDIO framework

The fundamental aim of the CDIO framework is to educate students who are "ready to engineer" and to raise the quality of engineering programs. See Crawley et al. (2014) and the web site CDIO Initiative (2023). The framework relies on four key components:

- A "definition" of the role of an engineer.
- Goals for the desired knowledge and skills of an engineer listed in the document the CDIO Syllabus (2023), which serves as a specification of learning outcomes.
- Goals for the properties of the engineering education program collected in the document CDIO Standards (2023), which work as guidelines of how to design a well-functioning engineering education.
- Methods for systematic development and management of education programs.

According to the CDIO framework, see Crawley et. al. (2014) page 50, the goal of engineering education is that every graduating engineer should be able to *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.* This formulation can serve as a definition providing the basis for the entire CDIO framework. Adopting the definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer. Via the sub-sections and sub-sub-sections, the document offers an extensive list of knowledge and skills, which can be used to specify learning outcomes of individual courses or education programs. The CDIO Standards (2023) is a set of twelve components that are necessary for designing and running an engineering program that enables the students to reach the desired knowledge and skills. The CDIO framework offers a variety of tools for development and management of education programs, including for example the so-called Black-box exercise and the CDIO Syllabus survey. These tools are described in some detail in Crawley et al. (2014).

CDIO WITHIN THE APPLIED PHYSICS AND ELECTRICAL ENGINEERING PROGRAM

Background

Linköping University was one of the four original participants in the CDIO Initiative, and during the first years the efforts were concentrated to the Applied physics and electrical engineering program. Gradually the framework was applied within other areas, such as Engineering biology and Mechanical engineering. See for example Hallberg (2018). The framework has been disseminated outside the engineering field, and it has been applied successfully in the re-design of the Bachelor's program in biomedicine, as reported in Fahlgren et al. (2019). Another example of the widespread use of the CDIO framework within Linköping University is that the CDIO Syllabus has been extended and adapted to enable for programs in, e.g., natural sciences to be included. The adapted version, the LiTH Syllabus, is a key component in the quality system, via the use of course and program matrices, as reported in Gunnarsson et al. (2019).

An important outcome of the re-design of the Applied physics and electrical engineering program was that a sequence of project-based courses was introduced in the program, in terms of an Introduction to engineering (see Standard 4) and design-implement experiences in year three and year four (see Standard 5). More detailed descriptions of the re-design are given in Gunnarsson et al. (2005). With the big emphasis on project-based design-implement experiences it was found motivated to develop a common project model, and this effort resulted in the LIPS model, which is a project model adapted for educational use. See the website LIPS (2023) and Svensson and Krysander (2011). In the LIPS model the project work is split into the three phases *Before*, *During*, and *After* with tollgates between the phases. The Before phase starts from a project directive with a, rather vague, description of what the customer wants to have developed. The main tasks for the student team during the Before phase is to interpret the project directive and formulate a requirement specification and to write a project plan and a time plan. After approval, at the decision point two, the team enters the During phase and the actual design and implement work starts. The work, which often includes several iterations, leads to the decision point five, which leads to the After phase in which the team is allowed to deliver the results. The reflection is a built-in evaluation step after the delivery of the project result at the end of the After phase. The main sections in the reflection document are *Time report*, *Fulfillment of the goal*, and *Summary of the three most important experiences*, where the last section contains the subsection *The three most important experiences* and *Good advice to those who are going to perform a similar project*. A template for the document is found via LIPS (2023), and the table of contents of the document is given in Appendix B.

Introductory Course

The development of the introductory course *Engineering project* (Swe: Ingenjörsprojekt) started almost immediately after that the CDIO Initiative had been launched, and the course was given for the first time during the fall semester 2002. The structure and organization of the course is described in some detail in Box 4.3 in Chapter 4 of Crawley et al. (2014). The course encompasses 6 ECTS credits, and it consists of the three main parts *lectures and seminars*, *project work*, and *project conference* respectively. The project work is carried out using a subset of the steps and documents in the LIPS project model, and the key documents are the requirement specification, the project and time plan, the technical documentation, and the reflection document. The student teams, normally six students, are put together by the course management, while other approaches for forming the teams are used in courses later in the program.

Student interviews

During fall semester of 2022 the Engineering project course had 133 participating students. The students came from the Applied physics and electrical engineering (Y) and the Biomedical engineering (MED) program. The course is constructed around 13 different projects and the students are split into 23 groups, consisting of 5-7 students/group. Three students from the different classes participating in three different projects where interviewed. The interview was carried out by email using a questionnaire, and the answers are summarized below:

Process for writing the document (corresponding to questions 1 – 3 in Appendix A)

For some students this was the first time they met a reflection document, but one student had worked with a similar document in high school. All groups wrote the document together, with some delegation among the group members. Thoughts and comments from all students in all three groups were added in the document where they together wrote the reflection document. The groups spend between 2-6 hours in writing the document.

Benefit in writing the reflection document (see questions 4 -5 in Appendix A)

All students appreciated writing the reflection document. It gave them the chance to reflect over new experiences. It was clear for some that their view of the project differed from how other students in the same group experienced it, and this helped them understand that group dynamic is a very complex process and very important for a successful outcome. The writing of the document also made a very defined ending of the project course, it "closed the bag" as one student said.

Use of the LIPS reflection template (see question 6 - 7 in Appendix A)

Writing the reflection document comes with some challenges. It can be noted that students find it difficult to correlate the time spent in the project with the estimated time. This is understandable since logging of working hours is mostly new for most first year students. One group thought it was difficult to remember early challenges when the document was written since several months had passed in the project. One group thought it was difficult in writing on how to use the LIPS model since they felt "they didn´t use it". This can partly be explained that among the 26 teachers involved in the different projects, the use and emphasize in implementing the LIPS model differs. Some are very accurate whereas some are more "relaxed", and this highlights a problem managing a course with more than 30 teachers involved.

Individual reflection and feedback (see questions 8 – 9 in Appendix A)

All students, except one group, thought it also could be good to write an individual reflection document as well. One aspect of this that was mentioned was that thoughts and ideas could be ventilated without any influence from other group members. This could be valuable especially if the group didn´t work in an efficient way. The group that didn´t see a benefit with an individual reflection document had a very good group dynamic and they were very much in agreement with each other. Most students also saw the benefit of writing a reflection document earlier in the course, midway through. It was considered to increase motivation within the group but also give the possibility to perform changes while the project was running.

Continuous group-based reflection and feedback (see question 10 - 11 in Appendix A)

When asked if they in a "structural way" had reflected over the groups' work they said that during their weekly meetings, where notes were written, they usually reflected over what had been accomplished during the last week as well as how the last meeting had been. Although one group mentioned that they "didn't work in a structured way" they still had meetings with notes, so in this sense they did work accordingly without really reflecting over it.

Future benefit from writing a reflection document (see question 12 in Appendix A)
When asked if they thought the reflection document would improve their work in future courses, they all agreed. They all reflected over problems and errors they did during the project, and they all saw the benefit of reflecting over this and use this know-how in their future work. To spend time so everybody agrees and knows what to do as well as to move the project forward, although they got stuck in specific details was an important lesson for one group. As one student wrote “The consequence of not doing your job is that it later on will come and hit you.”

Reflection document versus course evaluation (see question 13 in Appendix A)
The students write one common reflection document and one individual course evaluation (arranged separately by Linköping University). They all thought the reflection document was more detailed and gave better feedback to them, both as individuals and as a group. The general course evaluation was considered more general and more focused on how the course is structured (seminars, working environment, equality etc.) whereas the reflection document penetrated their work in their dedicated project.

Advice for next year students, corresponding (see question 14 in Appendix A)
When the students are asked what their most important advice for next year’s students is, there are a few common thoughts that are mentioned. Make the group work efficiently (group dynamic) and divide the work within the group, start work early in the project and use the skill and know-how from the supervisor (LiU teacher). Let it take time for everybody to find their role and listen to what all group members have to say.

Bachelor’s Project

The origin of this design-implement experience is the project course in electronics that was developed and launched during the first years of the CDIO Initiative. A thorough presentation of the course is given in Svensson and Gunnarsson (2012), and, as can be seen in the paper, the course has been very appreciated by the students ever since the start. During the first years the course comprised 8 ECTS credits, and because of the Bologna process to course was at a later stage extended to a 16 ECTS Bachelor’s project. In the expansion a module with engineering ethics was introduced. Also, a pre-study of a sub-topic of the project (communication, control, or sensors) was added as a preparation step before the actual project. Also, the complexity of the project task was increased. At the same time a Bachelor’s project in physics was developed and introduced, to a large extent following the structure of the one in electronics. Also, in these projects the reflection document is used extensively, but since this project runs over the spring semester it is not included in this study.

Design-Implement Experiences in Year Five

One more result of the CDIO Initiative was that a set of design-implement courses were introduced in the program, and there are now eight different courses for the students to choose from depending on which specialization they have chosen. Some early descriptions of courses and project outcomes are given in Enqvist et al. (2005) and Karlsson et al. (2006). A more recent example is presented in Larsson et al. (2017) where Massive MIMO technique for mobile telecommunication was tested in practice using sound waves. At the time of the Bologna process the courses expanded in size, and at the same time entrepreneurship was introduced into the courses, as described in Gunnarsson et al. (2010). The courses give 12 ECTS credits, where 9 ECTS correspond to the technical contents and 3 ECTS are given for the entrepreneurship part. This paper focuses on the Automatic control project course, which is the largest in terms of number of students with approximately 60 students each year. It is taken by the students in year five as the last course before the Master's thesis project. This increases the practical importance of the reflection document since the conclusions can be of use in the coming Master's thesis. Most of the projects in this course are carried out in collaboration with an external stakeholder, i.e., a company or research institute.

Student interview
In this case an interview was carried out on-site with one of the project teams. The team was selected as one of those consisting of students from different programs. The different programs represented in the group were Mechanical engineering, Applied physics and electrical engineering, and Computer science and engineering. The discussion was based on the questions in Appendix A, and the answers and discussions are summarized as follows:

Process for writing the document (corresponding to questions 1 – 3 in Appendix A)
The experience was somewhat different depending on which program the students follow, and whether the LIPS template or some other template has been used. In one program the reflection after the Bachelor's project was performed as an individual reflection. Since the writing has been straightforward in the fifth year's course the previous experience has not been that important. Approximately 4 – 5 hours were spent on writing the reflection document and it was performed sequentially among the students. The writing was to some extent distributed according to the sub-projects. Finally, the entire group came together and finalized the document.

Benefit by writing the reflection document (see questions 4 -5 in Appendix A)
It has been an opportunity to exchange and compare experiences and reflections and to structure the thoughts and to remember.

Use of the LIPS reflection template (see question 6 - 7 in Appendix A)
Some, partly overlapping, parts were merged, and some part was removed. The most difficult part was to describe the achievements since, for this group, the main goal of the project wasn't reached, and to balance the disappointment over this with descriptions of the sub-goals that were achieved.

Individual reflection and feedback (see questions 8 - 9 in Appendix A)
The benefit of an individual document would probably not have been that much in our case. The collaboration in the team worked very well, and the team members had similar levels of ambition. Maybe in case there had been problems in the team and if it would have been constructive.

Continuous group-based reflection and feedback (see question 10 - 11 in Appendix A)
The weekly project meetings have served this purpose, even though the reflections and items haven't been written down. The discussions during the weekly meetings have, for example, led to decisions about contacts with the supervisor or customer concerning revised requirements. Since there is already a substantial amount of documentation in the project and reflections are done via the weekly meetings, it is hard to motivate one additional document.

Future benefit from writing a reflection document (see question 12 in Appendix A)
Difficult to say, but one important experience documented in the reflection document is the difficulty in setting up goals and the importance of formulating sub-goals. Also, the importance of writing down experiences and reflections.

Reflection document versus course evaluation (see question 13 in Appendix A)

The course evaluation is entirely for the course management, but the reflection document is primarily for the team and team members. Maybe 60 – 40. Good to have it as a mandatory activity.

Survey

In addition to the interviews, a questionnaire was sent out to all students in the course, and 13 replies were received and those are summarized below.

Process for writing the document (see questions 1 – 3 in Appendix A)
All students that replied have previously written a reflection document. The benefit of this prior experience was mainly indicated as neutral, apart from two positive and two negative answers.

Individual reflection and feedback (see questions 8 - 9 in Appendix A)
Regarding individual reflections, the opinion among the students is divided, with half of the group positive and half of the group negative. Among those who are negative, the majority are strongly negative. When it comes to obtaining individual feedback, the students are leaning in the positive direction, with three neutral and five weakly positive. One is strongly positive and two strongly negative.

Continuous group-based reflection and feedback (see question 10 - 11 in Appendix A)
The majority, i.e., eight students agree to that there has already previously been performed structured reflection about the work of the group, while five do not recognize this. Nine students believe that it would have been beneficial to perform a reflection already halfway through the course, one is neutral, and three are negative to this suggestion.

Future benefit from writing a reflection document (see question 12 in Appendix A)
Only three students disagree to that writing the reflection documents in this and previous courses will help to improve the work in future courses/projects. The majority, seven, students are weakly positive and three are neutral.

Overall, the students are positive to writing reflection documents and many would also appreciate it earlier. The LIPS project model is known to require many documents, so it is expected that suggesting writing additional documents will not be popular. Individual feedback is considered somewhat positive, but we also expect that this can be somewhat sensitive both to give and receive. Only three out of thirteen students disagree to that they will perform a better work because of the reflections they have performed during their studies.

Master's Thesis

The reflection document at the end of the Master's and Bachelor's thesis was introduced around 2011 as a mandatory last step of the thesis work in all engineering education programs within the Faculty of Science and Engineering at Linköping University. One purpose is to make the student reflect upon the execution of the final major task before graduation, and a second purpose is to give feedback to the program management concerning how well the education program has prepared the student for the intended role as engineer. Initial observations about the outcomes and values of the reflection documents were presented in Kindgren et al. (2012). The instructions for the document have been revised, and the current version can be found via Reflection document (2023). The third generation, which is a web-based system, was launched early 2023. The structure of the document follows the sections of the CDIO Syllabus, which means that the students are expected to reflect upon their work based on the following items:

- The significance of knowledge of the subject for the execution of the degree project.
- The significance of your personal and professional skills and the approach you have taken for the execution of the degree project.
- The significance of working in a group and communication during the degree project.
- The degree project from an engineer's perspective – planning, development, realisation, and operation of technical systems, taking into account commercial and societal needs and demands.

For each of these items the students are supported by a set of questions. Finally, the students are asked to reflect upon the work process and the interaction with examiner, supervisor, and the external partner.

SUMMARY AND CONCLUSIONS

The use of reflection as a support for the learning process within the Applied physics and electrical engineering program at Linköping University has been presented and evaluated in a case study. Reflections are used in design-implement experiences in year one, three, and five and as the last component of the Master's thesis. The paper has described in some detail how the reflections are integrated in the program, and experiences from student perspective are collected via interviews with students from year one and year five have been presented. The most important observations from the interviews are the following:

- All students found it useful to write the document, with somewhat stronger emphasis among the students in year one. The writing gives an opportunity to compare each other's impressions and opinions, and the document also marks the end of the project.
- The weekly team meeting with agenda and notes gives one type of continuous reflection since the team discusses the outcome of the last week's work and discusses progress as well as difficulties.
- The opinions concerning using also individual reflection documents were somewhat mixed, but the students point out the potential value of such a document in situations when there are problems in the team.
- The quite large difference in opinion in using reflection document among year five students was a bit highlighting. The reason for this could be due to that they participate in different education programs, hence different study plan that emphasize differently, but it could also be something else. This could be evaluated further but was not in the scope of this case study.

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APPENDIX A – QUESTIONS IN THE STUDENT INTERVIEWS

1. Have you written a reflection document or any similar document before. If yes, in what situations(s) and has that been of any help in this case?
2. How much time have you spent on the writing of the reflection document?
3. How did you organize the work to write the document?
4. What benefit have you had from discussing and writing the document together
5. What do you see as the main use of the document?

6. Have you used all parts of the template?
7. Which parts were most difficult to write, and which were easiest?
8. Would it have been useful to also write an individual reflection document?
9. What benefit would you have had from giving individual feedback to the team members during the project? Would you have appreciated getting individual feedback from the team members?
10. Have you, in any structured way, reflected over the activities of the team during the execution of the project, and in such a case how?
11. Would it have been useful to write a reflection document also halfway through the course
12. Do you think you will do an even better job in future courses/projects by having written the reflection document?
13. How do you view the difference between the reflection document and the regular course evaluation?

APPENDIX B – TABLE OF CONTENTS OF THE REFLECTION DOCUMENT IN LIPS

1 Time report

- Time report over spent time
- Comparison between planned and spent time
- Distribution of the work between the project participants
- Evaluation of work distribution
- Collaboration in the group
- Collaboration with tutor and customer
- Theoretical problems
- Technical problems
- The project model Lips – use, comments

2 Fulfillment of the goal

- Summary of achievements
- How the delivery worked out
- How the study situation influenced upon the project

3 Summary of the three most important experiences

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A FRAMEWORK FOR A SUSTAINABILITY TRANSITION OF TWO ENGINEERING MASTER'S COURSES

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ABSTRACT

Sustainability, as a concept, is permeating most of today's human activities, including higher education. The increased importance put on sustainability depends largely on the increased awareness of the huge environmental, social, and economic challenges that humanity is currently facing. As is the case with most complex themes, the route towards the application of appropriate actions starts with enlightenment developed within education, where different engineering programs form important subareas. To address this, CDIO Syllabus 3.0 in general, but optional standard 1 in specific, does now to an even greater extent handle sustainability issues. This paper presents a framework that is built upon several key concepts that are strongly related to education for sustainable development (ESD) at the university level, such as key sustainability concepts (as defined by UNESCO), sustainability development goals (as defined by the United Nations) and constructive alignment (as defined by Biggs and Tang). The framework is applied to two engineering master's courses where sustainability concepts and development goals are integrated and constructively aligned in the learning outcomes, teaching and learning activities, and assessments. Through the analysis of the two courses concerning sustainability, the framework is shown to provide a means for the analysis of how sustainability is currently incorporated in a course, highlight what possible teaching/learning shortcomings exist, and help identify actions that can be taken to overcome these shortcomings. The objective of the framework is thus to support course managers in the development of appropriate actions related to sustainability.

KEYWORDS

Constructive alignment, Education for sustainable development, Sustainability competences, Sustainability transition, Standards: optional standard 1

INTRODUCTION

Sustainability is an increasingly important topic in today's world, and its impact on university teaching is becoming more and more evident. At university level, sustainability is being integrated into curricula across many different disciplines, including engineering. By teaching students about sustainability, universities are helping to equip the next generation of engineers with the skills and knowledge to create sustainable solutions for the future. Through a combination of hands-on projects, lectures, case studies, and internships, engineering students are being exposed to the principles of sustainability and learning how to design and build solutions with a long-term, sustainable perspective. By learning about sustainability, engineering students are better prepared to help create a more sustainable world.

To analyze the curricula of an engineering course with respect to its handling of sustainability issues, a framework has been conceived. It is built upon four pillar stones, namely *sustainability transition* (Sterling and Thomas, 2006), *competences in sustainability* (Rieckmann, 2017), *sustainable development goals* (UN, 2015), and *constructive alignment* (Biggs and Tang, 2011).

As a basis for the analysis of the framework and its applicability to the incorporation of sustainability in engineering programs, two courses taught at master's level at the school of engineering at Jönköping University have been chosen. The first course is *Industrial Placement Course* (IPC), which is a 9 credits course that runs in the third semester of the two-year master's program Software Product Engineering, SPE. The second course is *Industrial Product Realization in Collaboration* (IPRIC), which is a 6 credits course that runs the first semester in all of the six master programs at the school of engineering (i.e., Industrial Design, Product Development and Materials Engineering, Production Development and Management, Software Product Engineering, Sustainable Building Information Management, and User Experience Design and IT Architecture). Both courses have pros and cons when it comes to incorporating sustainability as will be demonstrated further on.

The rest of this paper is divided in four sections. First, the theoretical background of the four pillar stones of the framework is presented. Next comes a section on the analysis of the two courses applying the framework followed by a section on how to increase the sustainability content in the two courses making use of the previous analysis. Finally, a discussion section ends the paper.

THEORETICAL BACKGROUND

In continuation are presented the four pillar stones that the developed framework in this paper is based upon.

Sustainability transition

Sterling and Thomas (2006) identified four stages in the transition towards sustainable education in universities (table 1).

Table 1. Stages for the development of sustainable education in universities (Sterling & Thomas, 2006)

Sustainability transition	Response	State of sustainability (societal change)	State of education (educational change)
Very weak	Denial, rejection, or minimum change	No change	No change
Weak	'Bolt-on'	Cosmetic reform	Education *about* sustainability
Strong	'Build-in'	Serious greening	Education *for* sustainability
Very strong	Rebuild or redesign	Wholly integrative	Sustainable education

The strive should be to reach the higher stages in the transition, something that is further elaborated on in relation to the master's courses further on.

According to DuPuis and Ball (2013, page 65), it is essential to move from a simple *know what* to a more complex *know how* to increase the sustainability awareness among students. *Know what* implies 'a focus on sustainable knowledge and practice as simply gathering and imparting to students the right codified information [that] has led to confusion in the classroom'. This is sometimes known as a summative approach. *Know how* implies a move towards interactive and collaborative platforms that promote five key competences (Wiek et al., 2011), which are further described in the next section. Thomas (2009) recommends problem-based learning as a vehicle towards a deeper understanding of different topics in education in general and sustainable education in specific. This is sometimes known as a formative approach. In the case of the IPC, problem-based learning comes naturally as students realize work in a real work environment during a 5–10-week period. The same goes for the IPRIC course where problem-based learning also plays a key role in the development of a project in a multi-cultural, multi-discipline and holistic setting. More about this later.

Barth et al. (2007) describe that key competences, like the ones presented further on, are required for forward-looking and autonomous participation in shaping sustainable development. A possible problem is that some experts state that competences are learnable but not teachable. If this is the case, how can the acquisition of such competences be observed and assessed? Barth et al. (2007) describe key competences as the interplay of cognitive and non-cognitive components. The authors argue that the acquisition of cognitive components is traceable when constructing *mental models*. A challenge is to choose the most adequate model as there literarily exist hundreds of them. Likewise, the acquisition of non-cognitive components (which is an interiorization process) are traceable through *production/reproduction* and *reception/communication*. Hence, the students must be enabled to discover and analyze their own value system, and to revise it with respect to its adequacy to reality. Consequently, the implementation of suitable teaching/learning activities and assessment tasks would be a way of reaching stage 3 (strong) on the sustainability transition ladder (table 1).

Stough et al. (2018) present a number of pedagogical sustainability assessment approaches applied in a one-year master program that prepares students for a career in the international business world by developing students' (business) economic acumen, knowledge, and management skills (table 3). Some of these approaches are used, and others could be used, in both the IPC and the IPRIC courses.

Sustainability competences

In 2017, the United Nations Educational, Scientific and Cultural Organization (UNESCO) presented a publication on education for sustainable development, ESD (UNESCO, 2017). The publication outlines eight key sustainability competences (KSC) required to advance ESD (table 2).

Table 2. Key sustainability competences (UNESCO, 2017)

1	**Systems thinking competence**: the ability to recognize and understand relationships; to analyze complex systems; to think of how systems are embedded within different domains and different scales; and to deal with uncertainty.
2	**Anticipatory competence**: the ability to understand and evaluate multiple futures – possible, probable, and desirable; to create one's own visions for the future; to apply the precautionary principle; to assess the consequences of actions; and to deal with risks and changes.
3	**Normative competence**: the ability to understand and reflect on the norms and values that underlie one's actions; and to negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4	**Strategic competence**: the ability to collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5	**Collaboration competence**: the ability to learn from others; to understand and respect the needs, perspectives, and actions of others (empathy); to understand, relate to and be sensitive to others (empathic leadership); to deal with conflicts in a group; and to facilitate collaborative and participatory problem solving.
6	**Critical thinking competence**: the ability to question norms, practices, and opinions; to reflect on one's own values, perceptions, and actions; and to take a position in the sustainability discourse.
7	**Self-awareness competence**: the ability to reflect on one's own role in the local community and (global) society; to continually evaluate and further motivate one's actions; and to deal with one's feelings and desires.
8	**Integrated problem-solving competence**: the overarching ability to apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive, and equitable solution options that promote sustainable development, integrating the previously mentioned competences.

The first five competences are based on the work by Wiek at al. (2011). One could argue that the eight competences, if stripped from the word sustainability which appears in some of them, are valid within any context and not solely to sustainability. Key words that sum up the eight key competences are collaboration, reflection, holistic thinking, and self-awareness. Such words generally permeate most university courses and programs and should therefore not constitute any major hindrance when considering sustainability as a specific topic. The challenge to a lecturer is to come up with relevant examples and cases where students can elaborate around sustainability issues in a natural and transparent context.

Lambrechts et al. (2013) analyzed the existing competence schemes of three programs within two Belgian universities in the fields of business management, office management, and applied information technology. The results of the analysis showed that competences for ESD related to responsibility and emotional intelligence were widely integrated, while competences for ESD dealing with system orientation, future orientation, personal commitment, and action taking were virtually absent.

Table 3. Pedagogical sustainability assessment activities (Stough et al., 2018)

Passive learning (summative)		Active learning (formative)	
In class	**Out of class**	**In class**	**Out of class**
Formal lectures	Guided city tours	Group discussions with reporting	Interviews
Guest lectures	Company visits	Questions	Internships
Research	Participation in roundtables/company stakeholder	Brainstorming	
Forum/discussion panels		Teaching-learning conversations	
Cases discussed by instructor		Cases processed by students	
Blended learning		Voting	
Online discussions		Simulation games	
Film screenings		Class discussions	
		Group work	
		Self-study	
		Project planning on computer	

Sustainable development goals

The United Nations have defined 17 sustainable development goals, SDG (UN, 2015). Ideally, the ESD at university level should touch upon all the 17 SDGs. This, however, could be difficult to achieve within a single course. More likely, they should be addressed at program level (or school level), if possible. Kestin et al. (2017) have presented a guide on how to get started with the SDGs on a university or higher education institution level. The guide 1) covers a summary of what the SDGs are, why universities are crucial for the achievement of the SDGs, and the significant benefits universities can gain from engaging with the SDGs, 2) provides an overview of how universities can contribute to implementing the SDGs through their core functions of education, research, operations and external leadership, 3) provides a step-by-step guide to help universities engage with the SDGs and in particular develop an institution-wide framework for supporting SDG implementation, and 4) offers practical guidance and tools to assist universities engage with the SDGs, including how to map existing activities, how to engage with stakeholders, and how to report on SDG contributions. Kopnina (2018) discusses how the SDGs are reflected upon within existing sustainability programs at a vocational college, and at the undergraduate and postgraduate university levels in The Netherlands. Within all three institutions Kopnina integrated lectures on sustainable development with specific emphasis on the SDGs. The presented case studies offer a brief summary of the curricula for the different Dutch programs that help address the 17 SDGs. The results indicate that the SDGs are mostly too anthropocentric, do not consider non-human species, and do not go far enough in addressing unsustainability.

Constructive alignment

As briefly outlined in the previous sections, if one as a lecturer or program manager has the intention to incorporate sustainability at university level, the ambition should be to reach as high as possible on the sustainability transition ladder (table 1). Most, or at least several, of the key competences in sustainability should be covered, if not within every single course, at least to some extent at program level.

The task requested in any university course is to constructively align the intended learning outcomes (ILO), with the teaching/learning activities (TLA) and the assessment tasks (AT), as described by Biggs and Tang (2011). Also, the TLAs should have a clear learning focus,

The sustainability transition within the SPE master's program is outlined in this paper by describing some possible measures regarding ILOs, TLAs and ATs applied to two of the program courses, i.e., IPC and IPRIC. The UNESCO sustainability key competences are also contemplated as are the sustainability development goals, at least to some extent.

ANALYSIS

First some results related to sustainability issues in higher education are presented followed by a description of the two courses and how they look today in regard to sustainability. In the Results section, the steps taken to incorporate sustainability in the courses are presented.

Industrial Placement Course (IPC)

The student, the host company and the university work out a suitable assignment together, based on the business's needs and opportunities and on the student's skills and experience. The assignment is then discussed and approved. Some examples of typical IPC student assignments at a company are:

- Take part in and contribute knowledge into ongoing project.
- Conduct a study of an ongoing production process.
- Try different kinds of practical work that are relevant to the student's education.
- Participate in professional development in the company based on the student's previous courses and experiences.

In continuation, the ILOs, TLAs and ATs are described and analyzed.
Intended Learning Outcomes

Table 4 outlines the intended learning outcomes (ILO) for the IPC. It can be noticed that one of the ILOs explicitly focus on sustainability.

Table 4. Intended learning outcomes in the IPC course

Knowledge and understanding (KU)
Demonstrate an understanding of the difference between the experience of practical work and the theoretical knowledge acquired earlier in the program
Competence and skills (CS)
Demonstrate the ability to apply the knowledge acquired through their education in professional work
Demonstrate the ability to describe, analyze and reflect on the results of their work experience and to present them orally and in writing to the client and at the university
Judgement and approach (JA)
Demonstrate the ability, based on experience with clients, to reflect on their need for knowledge and skills in professional practice
Demonstrate insight into their future professional role and the responsibility for ***sustainability*** that comes with it

Teaching/Learning Activities

The IPC consists of the following teaching/learning activities:

- An introductory seminar
- 3 lunch seminars on how to find a placement, how to write a CV and how to behave during a job interview
- 5 weeks of work at a company or organization

Assessment Tasks

The IPC consists of the following assessment tasks:

- Write a report that includes two parts; one where the student presents his/her activities in the company and one presenting the student's reflection of the activities in relation to the program, taken courses and personal competences
- Present the work activities and reflections in a seminar
- Oppose on another student's report and presentation

As can be observed, only one ILO explicitly addresses sustainability. As can also be observed, the ILO is not explicitly addressed during the TLAs or ATs. Furthermore, the ILOs are not constructively aligned in a good fashion with the TLAs and the ATs. One main obstacle is the fact that the course is mainly conducted outside of the university campus at a company or organization, which means that most activities are 'invisible' to the course manager. This poses a special challenge when aligning the course, especially when it comes to the TLAs as all of them currently take place outside of the university campus. Currently, all ILOs are assessed in the final report and during a final presentation.

Industrial Product Realization in Collaboration (IPRIC)

The course covers the different stages in the product realization process and provides a theoretical, organizational, and scientific framework both generically and specifically for the different master programs. The course includes the following topics:

- Content, working methods and environment conditions of the stages in the product realization process
- Relevant product development, industrial design, and information technology methods
- Group dynamics, leadership, and communication in the different stages of the product realization process
- Multicultural aspects of communication and work

As stated earlier, IPRIC is a common and mandatory course taken by all students in all the six master programs at the school of engineering, involving some 160 students. The master programs include a large proportion of foreign students, coming from all over the world, something that is touched upon in some of the intended learning outcomes. In continuation, the ILOs, TLAs and ATs of the IPRIC course are described and analyzed.

Intended Learning Outcomes

Table 5 outlines the intended learning outcomes (ILO) for the IPRIC course.

Table 5. Intended learning outcomes in the IPRIC course

Knowledge and understanding (KU)
Demonstrate comprehension of the content, working methods and environment conditions of the stages in the product realization process
Competence and skills (CS)
Demonstrate the ability to analyze different forms of leadership and group's dynamics
Demonstrate the ability to work in a multicultural work environment
Demonstrate the ability to complete a project in a collaboration and meet the pre-determined objectives of the project
Judgement and approach (JA)
Demonstrate the ability to value and reflect over the result of the project towards pre-determined objectives
Demonstrate an understanding of how different skills in the product realization process contributes to the entire process
Demonstrate an understanding of how personal and cultural differences contribute to the outcome of development work

Teaching/Learning Activities

The IPRIC course consists of the following teaching/learning activities:

- Seven lectures (teaching) directly followed by a related seminar (learning) conducted by six different lecturers from different departments at the school of engineering
- One workshop (teaching/learning)
- Six multi-cultural competence training opportunities (teaching/learning)
- A project developed by teams of students (learning)

Assessment Tasks

The IPRIC course consists of the following assessment tasks:

- A project developed by teams of students
- An assignment developed by teams of students

The project covers the following topics:

- The students form teams consisting of participants from the six different master programs and with diverse cultural backgrounds
- The teams develop a project around one of three possible problems (contributing with their own domain specific competences), e.g.
    - Smart lighting panels in classrooms
    - Smart lighting panel in open office spaces
    - Smart lighting panel in residential spaces
- The work is entered in individual logbooks including
    - Experiences while conducting the project
    - Group dynamics during the project
- A presentation of the results

The assignment (in form of written individual reports) covers the following topics:

- Experiences while conducting the project
- Group dynamics during the project
- The students' own contribution during the project
- Student reflections on multi-cultural teams during the project realization
    - Positive aspects, benefits – how did the students utilize them?
    - Negative aspects, challenges – how did the students overcome them?

An analysis of the project and the assignment with respect to the key sustainability competences results in that the project to greater degree touches upon the (4) Strategic, (5) Collaboration and (7) Self-awareness solving competences while the assignment mostly touches upon the (1) Systems thinking, (2) Anticipatory, (3) Normative, (6) Critical thinking and (8) Integrated problem-solving competences. As can also be observed, the project acts both as a TLA (explicit learning) and as an AT activity (but some learning will implicitly take place during the group work) while the assignment is mostly an AT activity (but some learning will implicitly take place during the reflections). Yet another observation is that the multi-cultural group activities that take place during the development of the project act as a design experiment due to its iterative nature (Downing-Wilson et al., 2011). Furthermore, the teams also function as communities of learners due to the continuous discussions between the team members while they simultaneously assimilate the sustainability lingua franca through mutual appropriation (Downing-Wilson et al., 2011).

Regarding the constructive alignment between the ILOs, TLAs and ATs it should be noted that the TLAs provide the students with the necessary knowledge/learning experiences for them to be able to perform the ATs, thus forming a bridge between the ILOs and the ATs. The current ILO – AT alignment is outlined in table 6.

Table 6. Alignment ILO – AT

Intended Learning Outcomes	**Assessment Tasks**
Knowledge and understanding (KU)	
Demonstrate comprehension of the content, working methods and environment conditions of the stages in the product realization process	Project (Process)
Competence and skills (CS)	
Demonstrate the ability to analyze different forms of leadership and group's dynamics	Project (LGD) Assignment
Demonstrate the ability to work in a multicultural work environment	Project (MCT) Assignment
Demonstrate the ability to complete a project in a collaboration and meet the pre-determined objectives of the project	Project (Collaboration)
Judgement and approach (JA)	
Demonstrate the ability to value and reflect over the result of the project towards pre-determined objectives	Project (Implementation)
Demonstrate an understanding of how different skills in the product realization process contributes to the entire process	Project (Process)
Demonstrate an understanding of how personal and cultural differences contribute to the outcome of development work	Project (MCT) Assignment

LGD: Leadership and Group Dynamics, MCT: Multi-Cultural Teams

RESULTS

Industrial Placement Course (IPC)

The sustainability transition that is outlined in continuation is from stage 1 (no sustainability in the education) to stage 2 (education about sustainability). Stage 3 (education for sustainability) would be even more adequate and is briefly elaborated on at the end.

Regarding the currently taught and assessed competences coupled to sustainability, it could be argued that the only key competence that explicitly touches upon the learning outcome 'Demonstrate insight into their future professional role and the responsibility for *sustainability* that comes with it' is the 'anticipatory competence'. The other key competences could be regarded as implicitly touched upon in IPC (as well as other courses in the SPE program). This, however, is not entirely satisfactory, especially if one strives to reach stage 3, and even more so stage 4, on the sustainability transition ladder.

The eight key competences previously described often rely on collaboration between different stakeholders and are considered formative in nature. They also promote a deep approach to learning (Biggs and Tang, 2011) which is essential from a life-long, self-induced learning perspective. As IPC is almost entirely developed at a company/organization, the course needs to prepare the students for these collaborative activities. The activities should preferably be conducted during the start of the SPE program in a course such as IPRIC, which is described further on.

'Improved' competences (stage 2)

The 'best' way to improve the competences would be to incorporate some collaborative activities focusing on sustainability in the beginning of the course. However, such activities could be regarded as bolt-on (see table 1). The best would thus be to incorporate new activities in the IPRIC course. Having stated that, the following activities could be considered in the IPC.

<u>Teaching/Learning Activities</u>

- Add an extra seminar in the beginning of the course imparted by an expert in sustainability, to make the students aware of what is expected from them during the stage at the company/organization.
- Have the students evaluate how sustainability is implemented at a company/organization and what pros and cons that can be observed from this implementation.

<u>Assessment Tasks</u>

- Explicitly request a special part in the report, as well as during the presentation, with a deeper analysis of sustainability issues handled by the company/organization.

'Improved' competences (stage 3)

To deepen the understanding of sustainability, some more costly activities (timewise) could be implemented.

<u>Teaching/Learning Activities</u>

- Add an extra seminar in the beginning of the course imparted by an expert in sustainability, to make the students aware about what is expected from them during the stage at the company/organization (same as for stage 2 to prepare for the other activities). This could possibly be left out if implemented in the IPRIC course, presented next.

- Have the students evaluate how sustainability is implemented at a company/organization through a number of interviews with key persons.

Assessment Tasks

- Explicitly request a special part in the report, as well as during the presentation, with a deeper analysis of sustainability issues handled by the company/organization.
- Have a separate discussion seminar, possibly right after the 'ordinary' presentations, where only the sustainability findings are discussed between the students.

Industrial Product Realization in Collaboration (IPRIC)

As can be observed, no ILO explicitly addresses sustainability, as compared to the IPC. This is (potentially) a drawback that could be circumvented by adding one (or possibly several) specific ILO(s), as in IPC, by modifying one or several of the ILOs or by explicitly adding some 'sustainability' activities within the project/assessment. The first two suggestions would make it possible to reach stage 2 (bolt-on) while the last suggestion would make it possible to reach stage 3 (build-in). A combination of the three suggestions could also be contemplated. Because of the nature of the IPRIC course and its multi-cultural aspects, it could even be argued that the name of the course could be modified to ***Sustainable*** *Industrial Product Realization in Collaboration*. Having stated that, in continuation are outlined some possible activities that could be incorporated in the IPRIC course, to improve the sustainability transition process to reach the higher stages of the sustainability transition ladder.

'Improved' competences (stage 2)

As could be observed, IPRIC is currently not explicitly contemplating sustainability at all, thus barely reaching stage 1. Like the IPC, a simple and straightforward approach is to introduce sustainability by adding a specifically designed seminar on sustainability.

Teaching/Learning Activities

- Add an extra seminar taught by an expert in sustainability to make the students aware of what is expected from them during the development of the project.

Assessment Tasks

- Explicitly request a specifically designed part in the report, as well as during the presentation, with a deeper analysis of sustainability issues within the project.

'Improved' competences (stage 3)

A more formative approach would be to make use of the inherent opportunities encountered within the course, such as collaborative activities and integrated problem-solving. By having the students reflecting upon economic, social, and environmental sustainability aspects during the development of the project, all eight UNESCO key sustainability competences (KSC) would be touched upon, some of them to a greater extent:

1. Systems thinking competence (individual): would be developed (and assessed) in the assignment but to some extent also during the project.
2. Anticipatory competence (individual): would be developed (and assessed) in the assignment but to some extent also during the project.
3. Normative competence (individual): would be developed (and assessed) in the assignment but to some extent also during the project.
4. Strategic competence (group): would be developed (and assessed) during the project due to its multi-cultural nature but to some extent also during the assignment.
5. Collaboration competence (group): would be developed (and assessed) during the project due to its multi-cultural nature but to some extent also during the assignment.
6. Critical thinking competence (individual): would be developed (and assessed) in the assignment but to some extent also during the project.
7. Self-awareness competence (individual/group): would be developed (and assessed) during the project due to its multi-cultural nature but to some extent also during the assignment.
8. Integrated problem-solving competence (individual): would be developed (and assessed) in the assignment but to some extent also during the project.

In general, there should be a movement from instrumental to emancipatory teaching/learning/assessment activities (Wals et al., 2008), something that the key sustainability competences will bring about.

Teaching/Learning Activities

- Design specific activities that should be seamlessly incorporated in the lectures, seminars, multi-cultural competence development etc. An example of this could be to have the students reflect upon social sustainability from a multi-cultural perspective during the project development. This is a form of social learning activity where the students are learning by mirroring their own ideas, views, values, and perspectives with those of the others in the team (Wals, 2011). It is a fact that people in general, and students in specific, learn more from each other when they are different from one another than when they all think alike, but only when there exists a social consistency in the group. That is why the multi-cultural competence training opportunities are of special importance.
- Another possible activity that would incorporate environmental, economic, and to some degree societal sustainability would be to have the students evaluate the impact on sustainability by having them apply the new ISO 14008 standard to their projects (ISO 14008:2019). The standard specifies a methodological framework for the monetary valuation of environmental impacts and related environmental aspects. A paper on how this monetary valuation can take place was presented by Steen (2016). Environmental impacts include impacts on human health, and on the built and natural environment. Environmental aspects include releases and the use of natural resources. The standard specifically contributes to the sustainable development goal 11 (Sustainable cities and

communities) and 13 (Climate action). Three case studies presented in a report by Steen et al. (2018) could provide examples when creating a specific activity around this theme in the IPRIC course.

Several similar activities should be designed and incorporated into the course study guide. The details of these activities, however, are not further detailed in this paper.

Assessment Tasks

- Explicitly request a specifically designed part in the report, as well as during the presentation, with a deeper analysis of sustainability issues within the project taking into consideration the mainly group key sustainability competences, i.e. (4) Strategic, (5) Collaboration and (7) Self-awareness competences (formative, deep learning). The difference from stage 2 is that the written and oral reflections should be much more exhaustive, to be able to observe and assess the acquired key competences.
- In the assignment, the students should develop and reflect upon sustainability taking into consideration the mainly personal key sustainability competences, i.e. (1) Systems thinking, (2) Anticipatory, (3) Normative, (6) Critical thinking and (8) Integrated problem-solving competences (formative, deep learning). The difference from stage 2 is that the written and oral reflections should be much more exhaustive, to be able to observe and assess the acquired key competences.
- Have a separate discussion seminar, possibly right after the 'ordinary' presentations, where only the sustainability findings are discussed between the different teams.

Table 7 illustrates how the constructive alignment could look like in order to reach stage 3 (build-in) on the sustainability transition ladder.

DISCUSSION

As can be observed in the presentation of the two courses, i.e., IPC and IPRIC, the latter appears to offer the biggest opportunities to incorporate activities that will improve the sustainability awareness among the SPE students. An additional advantage is that the IPRIC course happens to be the very first course taken by the students, thus making it possible to establish the sustainability compass for the remainder of the master programs in general and the SPE program in specific. Thus, in theory, it should be less challenging to incorporate sustainability activities in the IPRIC course. This is the reason why IPC could, and should, be modified as far as possible, together with other courses within the SPE program, to be able to possibly reach stage 4 on the sustainability transition ladder (table 1). The final goal is to make the students action competent in sustainability (Bruun-Jensen and Schnack, 1997), i.e., that they have the means to independently, or in a team, act on sustainability issues, whether they be environmental, economic, or societal.

Table 7. Alignment of ILO – TLA – AT – KSC

ILO	TLA	AT	KSC
KU: Demonstrate comprehension of the content, working methods and environment conditions of the stages in the product realization process	Lecture Seminar Project	Project (Process)	4, 5, 7
CS: Demonstrate the ability to analyze different forms of leadership and group's dynamics	Workshop Multi-cultural comp. Project Assignment	Project (LGD) Assignment	1, 2, 3, 4, 5, 6, 7, 8
CS: Demonstrate the ability to work in a multicultural work environment	Workshop Multi-cultural comp. Project Assignment	Project (MCT) Assignment	1, 2, 3, 4, 5, 6, 7, 8
CS: Demonstrate the ability to complete a project in a collaboration and meet the pre-determined objectives of the project	Workshop Multi-cultural comp. Project	Project (Collaboration)	4, 5, 7
JA: Demonstrate the ability to value and reflect over the result of the project towards pre-determined objectives	Project	Project (Implementation)	4, 5, 7
JA: Demonstrate an understanding of how different skills in the product realization process contributes to the entire process	Workshop Multi-cultural comp. Project	Project (Process)	4, 5, 7
JA: Demonstrate an understanding of how personal and cultural differences contribute to the outcome of development work	Workshop Multi-cultural comp. Project Assignment	Project (MCT) Assignment	1, 2, 3, 4, 5, 6, 7, 8

One would assume that the more courses with a sustainability context the better and that the optimum would be to have sustainability permeate each and every course within a university program. This assumption, however, was disproved by Fisher and McAdams (2015) whose results indicate that the type of sustainability courses taken, not the number of courses, significantly impacts students' conceptions of sustainability. Courses that have an integrated and direct emphasis on sustainability – and its literature – seem to cause students to have the most expanded conception of sustainability. The results by Fisher and McAdams also indicate that gender, race, and age appear to play a role in the way in which students perceive sustainability. Hence, a multi-cultural, multi-disciplinary and holistic course like IPRIC seems to be an excellent choice to introduce sustainability.

Similar results to those presented by Fisher and McAdams, that courses that have an integrated and direct emphasis on sustainability cause the students to have the most expanded conception of sustainability, were presented in a study by Jung et al. (2019). The study examined sustainable behaviors and social responsibility perceptions among U.S. university students enrolled in construction-related courses. To measure the effectiveness of sustainable construction courses and learning outcomes, the study categorized students based on their experience of taking such course(s) and compared the results in terms of their level of environmental concerns, objective and subjective knowledge, and sustainable consumer behaviors. The authors' initial hypothesis was that students who had taken a course on sustainability would have greater levels of environmental concern and be more engaged in performing sustainable consumer behaviors. However, the results were quite the opposite;

environmental concern and sustainable consumer behavior scores were significantly lower among students who had taken the course than among those who had not. Regarding the results of the two types of knowledge, both objective and subjective knowledge scores were relatively low. There was no difference between the two groups in the objective knowledge scores and unexpectedly, subjective knowledge scores were significantly lower among students who had taken the course as compared to those who had not. This indicated that those students who had not been engaged in sustainability education felt more familiar with the topic than those who had the opportunity to learn about the subject. Strange as it may sound, the complexity of understanding sustainability concepts may have caused students to lose confidence and familiarity about the topic. The results indicate that it is an extremely difficult and delicate problem to incorporate sustainability in university education in such a way that there will be a positive and observable outcome of the studies. Thus, much time and effort must be spent on the careful design of the courses and the program curriculum if an engineering program strives to reach the highest levels of the CDIO optional standard 1.

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IS MY MASTER THESIS RESEARCH PROJECT SUSTAINABLE? INCLUDING SUSTAINABILITY IN "RESEARCH METHODOLOGIES"

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ABSTRACT

Training socially conscious engineers and researchers is a core objective of the Delft University of Technology. One of the long-term goals is to give sustainability a central role in all educational programs, acting as a connecting thread. The Faculty of Aerospace Engineering at Delft University of Technology is working towards this common goal through several curriculum changes. This study focuses on the integration of a sustainability learning module into the online course Research Methodologies. Research Methodologies is a self-paced master's course where students start their research project for their master's thesis. The intervention's aim was to encourage students to incorporate sustainability into their master's thesis projects. Students were introduced to the Engineering for One Planet framework and motivated to view their research project through a sustainability lens. The responses of the students to the online discussion questions and their final research plans were examined to determine the effectiveness of the intervention.

KEYWORDS

MSc thesis, research, sustainability, Optional Standard 1

INTRODUCTION

The Delft University of Technology places a primary focus on training researchers and engineers with a strong sense of social responsibility. According to the TU Delft code of conduct's core values of Diversity, Integrity, Respect, Engagement, Courage, and Trust (DIRECT), educators must not only teach students to focus on problem resolution but also to critically examine its societal implications.

As a result, one of the university's long-term goals is to incorporate the concept of sustainable development throughout all educational and research programs [1]. This is based on the understanding that engineering and engineering education play critical roles in the societal transformations required to ensure a healthy planet and sustainable living conditions for current and future generations.

This understanding is also critical to the CDIO (Conceive-Design-Implement-Operate) frame-

[1] `https://www.tudelft.nl/en/sustainability`

work (Enelund, Knutson Wedel, Lundqvist, & Malmqvist, 2013). The CDIO framework was introduced to guide the development of engineers and researchers so that they are not only technically proficient but also understand the context in which their work is carried out. For this reason, sustainability and sustainable development are part of all of the core CDIO standards (Malmqvist, Edström, & Rosén, 2020). The importance of engineering education and opportunities for sustainable development is further emphasized by Optional Standard 1 for sustainable development (Malmqvist, Edström, Rosén, Hugo, & Campbell, 2020). CDIO Optional Standard 1 says that the goals and learning outcomes of an engineering program must include key sustainability competencies.

The TU Delft faculty of Aerospace Engineering has already implemented a number of initiatives that reflect the key sustainability competencies. For example, in the bachelor's graduation projects, sustainability is included as an explicit requirement and grading criterion (Brügemann et al., 2005). The aerospace engineering faculty fully supports Green Team Aerospace, a student-led sustainability committee, and hosts frequent seminars and lunch lectures on sustainable development. Additionally, a master's level course on sustainability in engineering was introduced in 2022. The course provides students with a theoretical basis and practical tools to apply in the context of aerospace engineering.

Major research initiatives within the faculty also prioritize sustainability. Our university's researchers believe complex technological solutions can reduce aerospace's climate impact. The European Partnership for Clean Aviation, the world's most ambitious aviation research and innovation partnership, welcomed TU Delft in 2021. AeroDelft [2], a student team, is developing the first manned liquid hydrogen-powered aircraft to demonstrate emission-free aviation.

However, even with all of these activities, the societal and environmental implications of the students own research were not explicitly considered in master's thesis projects outside of the sustainability-focused research initiatives. Given the time and resources devoted to the master's thesis work within the master of aerospace engineering program, this is pertinent. As described by Audunsson, Rouvrais, Rudd, Kristjánsson, and Moschetta (2022) the main goal of the master's thesis project is to bring together the student's knowledge of the field and their personal skills and to prepare the student for professional engineering work.

Because sustainable development was not intentionally considered in master's thesis projects, students were left with an educational gap. This gap was recently discovered, prompting the intervention described in this paper. The intervention's goal is to bridge the gap by incorporating a new sustainability module into the introductory research methodologies course. Since this course is taken at the beginning of the master's thesis research, the changes in the course materials are intended to introduce some valuable changes in practice in terms of sustainable research at this early stage.

[2] https://aerodelft.nl/

INTERVENTION

Course Description

This study discusses the implementation of a sustainability learning module within the online course Research Methodologies. The course has a workload of 2EC (54 hours) and is taken at the beginning of the thesis research process. The course is given online and is continuously available so that students can adapt it to their own thesis timeline. The course aims to equip students with the skills and tools to become better researchers and to develop their own research projects. The learning outcomes, as stated in CDIO Standard 2 (Malmqvist, Edström, & Rosén, 2020), detail what students should know and be able to do at the end of their engineering programs. For successful course completion, the following learning objectives are defined:

1. Formulate a research question(s)
2. Correctly cite the literature relevant to the research field.
3. Select the appropriate research tools and methods
4. Set up a clear research plan

A more detailed overview of the content of the course can be seen in Figure 1. The new Sustainable Research section discussed in the current study acts as bridge between the content on sampling, data management and project planning. The conexion with data management is especially relevant since as discussed by Pommerening (2021), sustainable data management and storage are an important part of research and not much attention has been paid to this in the past.

In order to evaluate these learning goals, the assessment is done via a report where the student needs to introduce their research project, describe the state of the art, and point out the research gaps. Then relevant research questions are formulated, and the methods, set-up, and expected results are described. The report concludes with a motivated plan for their research. This report is graded on a 10-criteria rubric. Each criteria establishes five levels: missing, needs work, acceptable, good, and excellent.

Theoretical content

The framework "Engineering for One Planet" (EOP) was used as a starting point to develop the module content. The literature relevant to the EOP is sumarized by Reynante (2022). EOP is an approach to sustainable engineering that emphasizes the importance of considering the impacts of technology on the environment and society and developing solutions that are both environmentally and socially responsible. This approach views the planet as a finite resource and recognizes that human activities have the potential to deplete the planet's resources and cause harm to the natural environment.

The EOP framework emphasizes the importance of taking a holistic, systems-based approach to sustainable engineering and encourages engineers to think beyond the boundaries of their

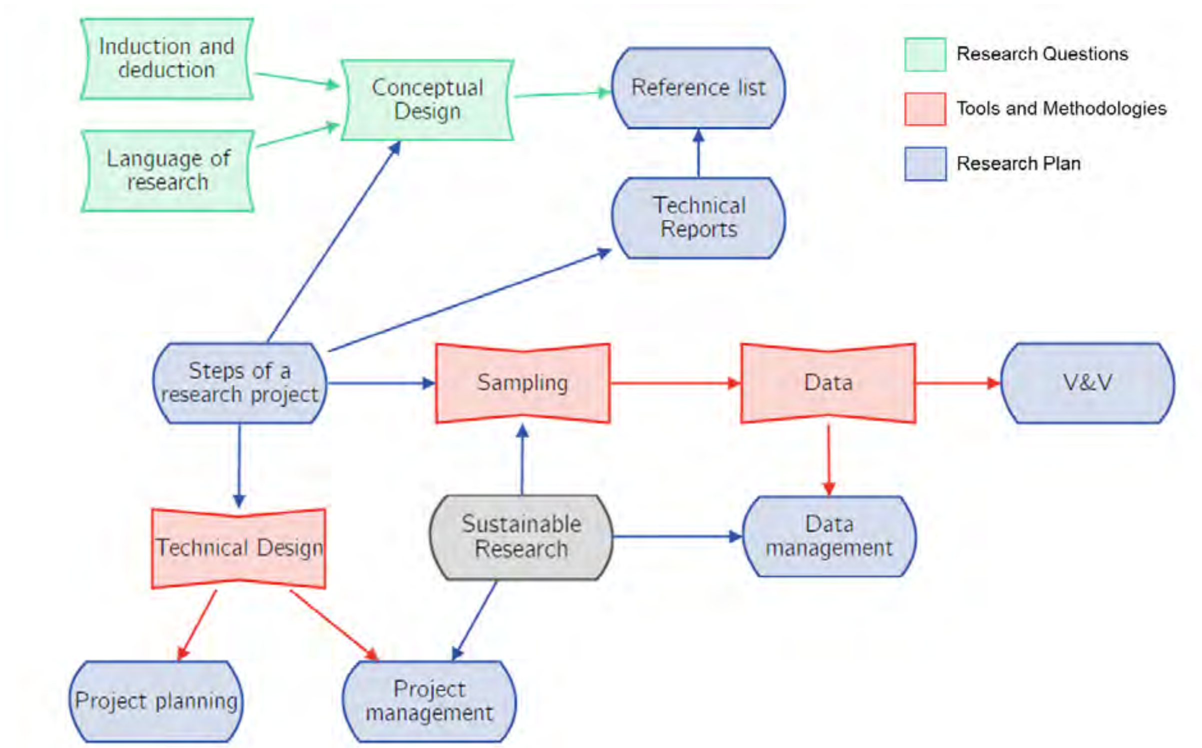

Figure 1. Overview of the Research Methodologies Course Content

own disciplines and consider the interconnections between technology, environment, and society. This corresponds directly to CDIO Standard 1 (Malmqvist, Edström, & Rosén, 2020), which stipulates that engineers must comprehend the implications of technology on social, economic, and environmental sustainability concerns in order to design acceptable technical solutions in conjunction with other actors.

The course's new sustainability module's materials encouraged students to think about the implications of their specific research's activities, bringing the often well-known but abstract and high level principles into concrete focus. Three things about research sustainability were included in the materials: the value of research, research resources management and the importance of reproducible research.

The first aspect, the **value of research**, emphasized that the first step to making research sustainable is choosing a relevant topic that has the potential to add value to the scientific community, the industry, and society. It is critical to ensure that the students can identify the potential for added value. Failing to do this can result in wasting time and resources on irrelevant findings. In order to accomplish this, they must investigate their chosen issue and be critical about the environmental, social, cultural, and/or economic implications of researching this gap.

The second aspect is the development of awareness of the **resources used** during the research project to help students make more environmentally conscious decisions. Resource management is related to research methods, but it focuses specifically on digital resources. Such resources include electricity, data storage, cloud computing, and other digital resources, which are increasingly utilized in modern research. Developing an understanding of the most efficient ways to use digital resources is beneficial not only for creating a sustainable environment but also for students' future work. Given the broad nature of the research methods used in the faculty of aerospace engineering, the materials regarding the use of resources are still of a high level. A much higher focus and specificity needed to induce a concrete change in practice are left for future iterations of the module content.

The final aspect is conducting **reproducible research**. This is an important aspect of ensuring that any research work has future value because not only does reproducible research indicate transparency and rigor in the research, but it also allows for additional research exploring similar topics to be conducted using fewer resources (Alston & Rick, 2021). By conducting reproducible research, more efficient collaboration with supervisors, reviewers, and potential researchers who would like to conduct supplementary analyses is possible. The material focuses on sustainable data management practices as well as specific open science best practices. Formerly, such resources were not available in the aerospace engineering master's curriculum and supervisors provided ad-hoc feeback related to this issues.

Learning Materials

Since the course is completely self-paced and online, much attention was placed on the development of efficient learning materials for this module. This was done by ensuring a clear outline of the topics covered, providing detailed descriptions of each subject, and making use of interactive tools to engage students.

The course already used a mix between short videos, in-depth texts and interactive activities. As discussed by Wiger, Gillström, and Sallnäs (2022), video lectures have many advantages in modern education but they are accompanied by their own challenges and pitfalls. The advantages of using video is that students have the opportunity to repeat specific parts that were more difficult to understand. Wiger et al. (2022) discussed that being able to pause and rewind the videos reduced the stress for the students.

However, in an online course where there is no face-to-face interaction between instructor and student, a diversity of materials is necessary. For example, there is the concern that teaching only through videos won't work for all kinds of learners. Videos should include support activities for processing the content, avoiding one-way communication in which students process the videos without receiving feedback on their learning. To create a successful online learning environment, a thoughtful mix of available learning experiences must be designed.

Short videos were the first material to be developed. The content was split so that none of the videos were longer than 10 minutes. This ensured that each video discussed only one or two key concepts. For the lecturer, the advantage of using short videos is that it allows for faster rerecording. This also allows for an easier update of the course content. The videos always start and conclude with the key concept discussed and include an example from the faculty of aerospace engineering. Accessing the videos was mandatory to progress in the course content.

Then, **in-depth texts with questions** were developed. The text provided was composed of lecture notes produced by the instructor and fragments of textbooks relevant to the topic (e.g.:Pommerening (2021)). Moreover, to add an interactive element to the reading experience, in this intervention, the in-depth texts were coupled with questions. The questions range from multiple-choice questions to open-ended answers. The questions were mainly used to facilitate the processing of key concepts. They were also thought to be valuable in sparking reflection and creating an online community among the students. FeedbackFruits was the tool used for this purpose. Although access to the text was required, answering the questions and responding to the discussion points were optional and anonymous.

The module was closed with a **self-assessment exercise**. Self-assessment exercises can help students assess their own progress and understanding of the course material. There were two main differences between the self-assessment and the questions asked in the texts. The first difference is that completing all questions of the self-assessment was mandatory to proceed with the rest of the course. The second difference was that the results of the self-assessment questions were not collected, and thus they can't be described in this paper. The self-assessments were short, relating each question to the key concept outlined in each video of the unit.

Finally, all the course material was complemented with an **open online forum**. Students used this tool more for course logistics than for content questions.

RESULTS

The intervention was implemented in the student cohort of the 22/23 year. Only the results of students who had already been assigned a grade were studied, as advised by the TU Delft's Human Research Ethics Committee [3]. This restricts the current evaluation to the students who submitted by the first deadline of the year, which is 64 out of the 463 enrolled students. There are two types of results discussed here: the engagement with the interactive material and the impact on the assessment.

Engagement with the interactive material

The engagement with the interactive materials was related to the in-depth texts described in the learning materials. Accessing this material was mandatory, but answering the questions was anonymous and voluntary. There were two ways the questions were asked: multiple-choice questions and open-ended answers.

Participation on open-ended questions was expected to be lower than that on multiple-choice questions. Therefore, the balance between both types of questions was set up to be 1 open-ended question per 5 multiple-choice questions, with a minimum of 1 open-ended question per text provided. In the current intervention, no question went unanswered. The lowest participation in a question was 6 students out of 64 (9.4%), while the largest participation was 33 students out of 64 (51.5%). Students either did not engage at all or engaged with at least three or more questions.

The multiple-choice format questions could be divided into two groups: questions to consolidate key concepts and questions to spark reflection. There was no significant difference in the

[3] https://www.tudelft.nl/en/about-tu-delft/strategy/integrity-policy/human-research-ethics

answer rate for the different types of questions. Some examples of this type of question are:

Content Consolidation Question: Is it always best to choose the least amount of resources? (Correct answer: No). Percentage correct answer: 87.5%.

Feedback given after answering: "You must strike a balance between the amount of resources used and the need to conduct valuable research. An optimal amount must be carefully considered. If you use fewer resources but your research is not valuable, then your research process is not as sustainable as it could be. If you use a larger number of resources than required for high-quality results, then your research is also not as sustainable as it could be."

Reflection Question: Had you ever considered your digital habits from a sustainability perspective? (No correct answer) Percentage Yes: 33.3%.

Feedback given after answering: "You might not have considered it, but there is a high chance your laptop is your most used resource during your research. Digital habits have a big impact on your research and should be considered as carefully as any other tool when drafting your research plan."

The purpose of the open-ended questions was different, since there were fewer of them and the participation was expected to decrease. In this case, there were also questions to spark reflection, but the primary objective was community building. Although all the responses were anonymous, they were assigned an alias so students could see their peers' answers and react to them either by liking the response or by directly answering it. Some examples of these questions are:

Reflection Question: Would you feel responsible if your research is used for (harmful) unintended purposes? (No correct answer) 10 answers out of 64 students (15.6% response rate)

Example student answers:
"Depends, if the technology is not by itself harmful, but it requires a choice made by someone else to be harmful, than that person would be responsible. If the technology can do harm on its own and then is used for bad stuff, then it's also my responsibility"
"Yes, to an extent. Ultimately, a lot of technology could be used for harmful purposes, and it is up to the scientific community to safeguard technology and limit the potential harmful implication"

Community Building Question: Do you have a particular system for this [organizing your own data] that you would like to share? (No correct answer) 6 answers out of 64 students (9.4% response rate)

Example student answers:
"I usually use a lot of nested folders, organized by topic and then (if needed) by date. All of this is contained in the names of the folders, and sometimes I add ReadMe.txt files. Then, I save the files themselves using no spaces or special characters to ensure compatibility with different programs in post processing"
"For my literature study, I have composed a list of sources which includes autor names, article/book titles, a short description, weblink if applicable and publication year. Each of these sources has been given a descriptive code e.g., PROP-01 or COST-04, and several have been

saved to to my drive under their respective codes."

Impact in the assessment

Another important metric for the intervention was whether students included sustainability concerns in their research project plans. This was not explicitly included in the rubric used for assessment. However, the project plan template suggested that there were three places where concerns about sustainability could be addressed: in the introduction section, in the section on methodology and set-up, and in the section on expected results.

In the introduction section, students are expected to discuss the relevance and value of their research. This is related to the first aspect described to them in the theoretical content of the sustainability module: the value of research. It was analyzed if students included environmental or societal concerns as drivers in the values of their research and if they explored the intended and unintended consequences of their research. From the student cohort studied, only 27% explicitly included sustainability notions related to the value of research in the project plan. However, a large number of research plans did include the expected impact of their research. There was a lack of interdisciplinary approach to their description; most of them failed to see the interconnections between different stakeholders, and they mostly presented the relevance from their field's perspective.

In the methodology and setup section, students are expected to discuss the methods and tools specifically used to perform their research. This is related to the second aspect described to them in the theoretical content of the sustainability module: resources. It was analyzed if students included environmental or societal concerns as drivers in their choice of methods and set-up. Surprisingly, the percentage of students who included sustainable methods and setup in their reports is remarkably low: only 6% explicitly addressed it. A possible explanation for this is that students prioritized describing accurately the methods and set-up and did not think it relevant to discuss the sustainability considerations. Furthermore, the majority of research plans were focused on the technical aspects and lacked discussion of how their methods and practices would impact society.

In the results section, students are expected to anticipate the potential results of their research and their desired outcomes. The verification and validation of their results, as well as the data management practices, must be defined. This is related to the second aspect described to them in the theoretical content of the sustainability module: reproducible research. It was analyzed if students included sustainable data management practices in their results discussions. Sustainable data management practices were included in 34% of the students' project plans. This was also surprising because students had not yet encountered this aspect of sustainability in their studies. The higher percentage can be attributed to the content's inclusion of practical examples and test cases.

Finally, 28% of students mentioned at least one criteria, 8% mentioned two, and 3% mentioned all three. The majority of the course 55% did not mention explicitly any of the key sustainability criteria.

DISCUSSION AND FUTURE WORK

In the final feedback form, students showed a positive response to the new sustainability module. A majority found the new videos and in-depth texts with questions to be useful. The results of the interactive section showed a moderate level of engagement, especially considering the interactive activities were voluntary. This indicates that the module was successful in capturing the students' attention towards the material. In the next iteration of the course, participation in at least one question of the module will be mandatory in order to proceed with the course. It is expected that this will raise the engagement of the students with the course content.

Unfortunately, the assessment analysis revealed that only a minority of students discussed their research projects through a sustainable lens. Only projects that take part in one of the sustainability initiatives thoroughly discuss sustainable development in their research plans. This shows that, even though the interactive module told students how important sustainability is in research, it wasn't enough to make a lasting impression on most of them because they didn't fully engage with the idea.

These findings are thought to be the result of the grading rubric's lack of explicit sustainability criteria. Because the grading rubric did not specify how sustainability should be evaluated, students had no incentive to incorporate sustainable thinking into their projects, even if they were aware of its importance. As a result, when it came time to evaluate the research plans, instructors couldn't accurately measure how much thought had gone into sustainable development and couldn't provide feedback that encouraged further sustainability considerations. Therefore, the work in the next iteration of the sustainability module would be to include it directly in the rubrics of the assessment.

CONCLUSIONS

The integration of a sustainability learning module into the online course Research Methodologies at Delft University of Technology has shown promising results in promoting socially conscious research in engineering among their master's students. The use of the Engineering for One Planet framework helped students view their research projects through a sustainability lens in three specific aspects: the value of their research, their research resources and the reproducibility of their results.

The responses of the students to the online discussion questions and their final research plans showed an improved understanding of the importance of conducting sustainable research. This study highlights the limitations on the effectiveness of the integration of the sustainability learning module and serves as a valuable example for other universities looking to promote technological innovation with a concern for society and research. This intervention helps the Faculty of Aerospace Engineering at Delft University of Technology reach its goal of making sustainability a central part of all educational programs, even if more improvements to the module still need to be performed.

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CHEMICAL ENGINEERING EDUCATION: PEDAGOGY FOR LEARNING FROM FAILURE IN PROCESS PLANT OPERATIONS

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ABSTRACT

The aim of this paper is to propose a pedagogy based on learning from failure to develop the confidence and competency that graduates from the Diploma in Chemical Engineering needed to function effectively in their job role as process technicians in the chemical processing industries. It is further suggested that the CDIO Framework can be used to achieve this aim. The paper first highlights the danger of losing vital cognitive skills due to increased automation and digitalization; and also explains the limitation of learning using simulations, despite these being the most dominant way of preparing students for work. Next, it introduces the concept of learning from failure; and argued that the prevailing approach of “Learning from Accidents” is not always effective, especially when one lacks the necessary scientific knowhow and understanding of complexities of issues involved. The modular way of teaching, where different engineering fundamentals (e.g. fluid flow, heat transfer, etc) are taught in separate modules by different lecturers, often resulted in the opposite outcome: “designing out failure”. Problem solving often means working through questions that focus on applying the correct equations within the confine of the respective module; often neglecting the need to use valid data. Students are not taught to integrate the knowledge until later year of study by creating a computer model of a chemical plant. This paper then suggests a pedagogy for learning from failure that can be formulated to sensitize students to the notion of failure as a form of learning, rather than as an outcome to be avoided. In the context of chemical plant operation, this means that one must be able to make sense of big data, notably the relationships between process variables in plant operations. This will address the issue of “unknown knowns”, referring to situations where students were unable to see the connections between knowledge learnt from different modules in problem analysis. This paper illustrates how the CDIO Framework, along with a set of principles for learning from failure, can be used to design an integrated curriculum that progressively develop a new “failure-tolerant” mindset, using integrated learning experiences infused with “deliberate failure” to scaffold learning in process plant operations. Such learning can start with students being aware of interdependencies of various process variables, moving on to interactions between different plant equipment during operation. This paper concludes with discussion on how such new mindset can be further developed using the pedagogy presented.

KEYWORDS

Learning from Failure, Digitalization, Chemical Engineering, CDIO Core Standards 1, 2, 3, 7.

NOTE: Singapore Polytechnic uses the word 'courses' to describe its education 'programs'. A 'course' in the Diploma in Chemical Engineering consists of many subjects that are termed 'modules'; which in the universities contexts are often called 'courses'. A teaching academic is known as a 'lecturer', which is often referred to a as 'faculty' in the universities.

INTRODUCTION: THE CONTEXT

Today's education is struggling to keep up with changes, mostly notably brought about by the Fourth Industrial Revolution, Sustainable Development and Globalization. This is particularly true for engineering education, due not only to technological advances but also because of the increasing need to include learning from other disciplines such as humanities and the arts; all the while still having to retain the basic scientific principles and engineering fundamentals. Gajek, et al (2022) suggested that the main future competencies required for the training of chemical engineers in relation to Industry 4.0 technologies are digital competences (process software and system safety, ability to handle IT security and safety), soft competences (with culture, leadership, communication and organization) and the business or management competences, such as decision-making, complexity). In short, skills and attitudinal aspects are increasing need to be integrated into an already-packed curriculum to provide the suitable context for learning. Digital competencies in particular, is now a priority area in chemical engineering education (Zandi, et al, 2022). This often begs the question: What are the "fundamentals of fundamentals" that students need to know, as far as technical knowledge is concerned, to remain competent, and confident in tackling workplace issues?

The chemical processing industry is a high-risk one: it often deals with materials that are toxic and flammable, under conditions of high pressure and temperature. Advances in technologies had resulted in more integrated chemical plants and had over the years, made the operation safer. Ironically, this means that the probabilities or likelihood of an incident happening is low; but the consequences will be very high should one occurred. Moreover, there is no way to eliminate risk completely. Hence, it is of paramount importance that employees are effectively trained to respond to process plant upsets in a timely manner; to take proper corrective actions to prevent escalation of the situation. A process may spin out of control, leading in loss of containment that can result in toxic and/or flammable releases, fires and explosions.

This paper specifically explored the area of chemical processing plant operations in the age of digitalization, characterized by availability of big data; and the need to make sense of these data for better decision-making. Use of machine learning (ML) such as neural networks coupled with artificial intelligence (AI) will enable the rapid processing of large big data fed by numerous sensors, execution of pre-programmed algorithms, and displaying the status of the plant in real time on dashboards.

This paper stressed the importance of better preparing our students so that they are not only technically competent but more importantly, confident in interpreting these data especially during process plant emergencies. The efficiency of the ML/AI system will put the deluge of data through pre-programmed diagnostics, offer possible causes and recommend plausible corrective actions. It is therefore important that chemical process technicians remain confident and be able to interpret these rapidly evolving events to make sense of them; and make the correct decision among the choices available.

To this end, this paper proposes a pedagogical approach for training students in chemical process plant operation, using failure as a mean to stimulate learning, motivating them to learn the fundamentals of chemical engineering. Indeed, learning from accidents is already an important approach for the chemical industry, but the effect of digitalization makes such learning even more urgent. This paper suggests that the traditional approach of learning from accidents needs to be improved, and that such a pedagogy can be developed using the CDIO Framework. It is envision that other engineering disciplines can also adopt and/or adapt the underlying principles in the proposed pedagogy for their respective programs.

DIGITALIZATION AND COMPETENCY IN CHEMICAL PROCESS PLANT OPERATIONS

The Diploma in Chemical Engineering (DCHE) of Singapore Polytechnic is a 3-year program that produces graduates that work in a range of chemical processing industries. Graduates from DCHE typically found employment as Process Technicians, Technologists or Engineering Assistants. Many students also further their studies in the universities earning a degree in chemical engineering; and joining the industry as Chemical Engineers. Equipped with the basic knowledge from formal education, it took many more years to build up the expert knowledge to become a professional. In other words, human understanding is progressing at a far slower pace compared to the time it takes ML and AI to codify many years of experience – especially tacit ones – into a set of heuristics that guides the day-to-day operations of the chemical plants (e.g. predictive maintenance) and troubleshooting operational issues.

In a way, the problem depicted above is not very different from that challenged the aviation industry, where increased automation had increasingly taking over the functions of pilots in airlines. In his book *The Glass Cage*, Carr (2014) had argued that our increasing dependency on computers and technology is causing us to lose vital skills. While the automation of flying has made air travel safer, it has also resulted in the loss of cognitive control and lack of situational awareness among pilots. In some cases, such disconnect can have dramatic consequences: when an error occurs or the software fails to work as intended, manual control is abruptly thrust back into the hands of an overwhelmed pilot (Borowski, 2013). The recent aviation disaster that of the Boeing 737 MAX, reminds one of the question posed by Carr (2014): How will pilots react to a scenario that they were not trained for?

Like the aviation industry and the nuclear industry, the chemical processing industry also faced the challenge of managing risk where time-sensitive matters demanded timely human intervention that correctly address the developing emergency: Failure is not an option. This begs the question of whether engineers have the confidence in diagnosing an event he/she had never encountered before, and decide on the correct course of action to take, or for that matter, choose among several options as suggested by the company AI system. Already the chemical industry is grappling with the challenge of alarm management, where operating personnel are struggling to respond to the flood of alarms of all sorts (Noda, 2012; Jofriet, 2005).

Carr (2014) warned of the 2 threats confronting humans when using technology without thinking about them: *automation complacency* and *automation bias*. Automation complacency takes hold when a computer lulls us into a false sense of security. We became so confident that the machine will work flawlessly, handling any challenge that may arise, that we allow our attention to drift. Automation bias is closely related to automation complacency. It creeps in when people give undue weight to the information coming through their monitors. Their trust in the software becomes so strong that they ignore or discount other sources of information, including their own senses. It is the notion that because a result comes from a machine, it must be correct. We forget that the result may be flawed because it can only be as good as the algorithm under which it operates (Huth, 2016). The proliferation of advanced Industrial Internet of Things (IIoT) technologies such as smart sensors and transmitters are poised to exacerbate the situation with the big data they generated if not managed well.

This is in particular important to guard against a phenomenon known as the "watermelon effect" (Ellis, 2018) that arises from increasing use of dashboards to monitor chemical plant performance. The concern is the dangers of operating personnel not challenging apparent good performance, as indicated by the green outer layer of the watermelon, which represents indicators suggesting: "all is well". However, deeper digging will reveal a red flesh inside indicating potential problem areas hidden from view, hence conveying a false sense of security. When problems do surfaced they represent dire situations that demanded quick resolutions, but human minds may be overwhelmed by the deluge of alarms.

LIMITATION OF TRAINING USING SIMULATION

Simulation-based learning had been widely studies, and recent report by Chernikova, et al (2020) reaffirmed its usefulness in promoting learning across higher education domain. In the chemical industry, simulation had been used successfully and effectively to train students in virtual plant operations in dealing with various problems in the plant. Simulations lend themselves readily to such trainings, as they are able to provide authentic scenarios that are not possible in the classroom, as the processes in the chemical industries are often carried out at high temperatures and pressure, for a wide range of chemicals many of which are toxic, flammable and/or explosive.

It is important to note that competency arising from such training needs to be supplemented with real-world work experience; which often takes many years to develop. For process technicians, this means performing various roles in the chemical plant, gain intimate working knowledge by utilizing their senses, notably sight, sound, smell, and touch. The use of IIoT technologies will drastically change the nature of work typically performed by process technicians in the plant. Use of smart sensors and controllers had not only taken over monitoring of the usual process variables of flow rates, temperatures, pressures, level, etc; but also those parameters usually carried out by process technicians during the routine walk-around the plants, such as functioning of steam traps, vibration of motors, etc.

Compared with the aviation industry, the chemical processing industries has many more plants that are different compared to aircraft types, handling large number of chemicals. Hence, it is impossible to train students in every conceivable chemical plant configurations, or chemical products. Even if one groups these plants into several categories based on the chemical products made, the number of different plants are still very large. As such, besides proprietary build simulators that are only available to company employees, much of the simulators available commercially focused on common chemical processes such as distillation, absorption, etc. Not only that, the cost of acquiring such training softwares even with academic discounts is still prohibitively large for widespread adoption in the universities.

For all the benefits accrued to simulation-based training, one must be mindful that the models were usually created based on known events, much like the aviation industry where the consequences had been experienced or studied; and procedures had been developed to deal with such an incident. As such, simulation-based training often emphasized executing a series of prescribed steps in operating manuals, i.e. the focus is aimed at preventing failures. Although a typical simulation package will include responding to process malfunction scenarios, still these are based on well-known operational problems such as loss of cooling water or pump trip. Indeed, Choudhari (2020) cautioned on the risk of inexperienced engineers relying on blind faith that simulations will deliver the right output.

It is common belief that simulators can provide sophisticated and accurate results in the shortest time, often unaware of the limitations and capabilities of a selected method or a selected equation. Likewise, Silverstein (2004) noted that there “appears to be a bias on the part of students towards trusting expensive simulator packages without considering how simulators work, what models are used, what assumptions are made, or potential sources of numerical error”. Today’s simulators are very sophisticated that to utilize its capability, adequate knowledge and specific process experience has become a prerequisite (Choudhari, 2020). Even so, the complexity of integrated chemical plants mean that it may not be possible to identify all possible interactions between the individual process units and hence to prepare students for all possible scenarios.

The training using process simulators for chemical plant operations often go along these steps:

- Students familiarize themselves with a given chemical process for which a simulation model is built. Such a process is typically a “generic” one, which in the case of distillation can be a simple 2-component separation of simple hydrocarbons or more complicated multi-component crude oil separation. A model for gas absorption typically involve the removal of hydrogen sulfide gas from a mixture of hydrocarbon gases. A simulation involving chemical reaction is typically one of a fixed-bed reactor for removal of sulfur compounds from a diesel product. These are the common models for processes typical in a refinery. Models are also available for the production of petrochemicals and fine chemicals. The bottom line here is that students must first learnt the process, equipment involved, operating conditions, feed materials that are used, and specifications of the desired product(s).
- Training usually starts with understanding how to operate the plant, by starting the simulation in “steady-state” mode, a condition whereby the process is running smoothly. Students start to make small changes to the plant, for example; changes in composition of the feed materials in a distillation unit, raising the flowrate of a solvent to a gas absorption unit, or increasing the operating temperature of a chemical reactor. Students observe how the entire process respond to these deliberate changes by monitoring various trend graphs generated by the simulator.
- The next phase of training then go into learning about malfunctions, and how to respond to them. This usually made use of several scenarios already available (pre-programmed) from the simulation package, and students go through a step-by-step process of rectifying the situation to bring the process back to its steady-state condition. Under a malfunction scenario situation, students must interpret the cause of alarms that were triggered, which can indicate deviations from desired operating conditions or potential issues with certain equipment; and they need to make sense of the myriad of data to pin-point the root cause and then take corrective actions. Students get to connect the observed data with a given type of malfunction.
- The last phase often involved an unknown issue being triggered, and students need to troubleshoot the situation to arrive at an acceptable way to address the issue. Often this is based on any one of the malfunctions that students had practiced before in the earlier phase. This phase may sound rather straight forward, as it appears that students already “make the connections” between a given malfunction and the observed plant performance. In practice, it is more challenging, as different malfunctions often give rise to the same alarms being triggered, as the process variables are all interconnected and can affect one another. The challenge becomes one of identifying the initial triggering event and reason through the malfunction process to ascertain the best corrective measure to take.

LEARNING FROM FAILURE: LITERATURE REVIEW

The chemical industries had consciously documented all major and minor accidents as well as near misses with the aim of making all processes safer. In order to prevent accidents it is essential to learn from previous accidents and incidents. Learning from accidents is to extract, put together and analyse and also to communicate and bring back knowledge on accidents and near-accidents, from discovery to course of event, damage, and cause to all who need this information. The purpose is to prevent the occurrence of similar events, to limit damage, and thereby improve safety work (Lindberg, et al, 2010). Learning from accidents are normally introduced through case studies (see for example, Weibull, et al, 2020; Kletz, 2001; Jefferson, et al, 1997). However, despite the numerous books and other publications on the topic, many organisations still faced challenges in reducing the number of safety incidents.

This can be attributed partly to the failure to learn from accidents (Drupsteen, et al, 2013). Barriers to learning from incidents and accidents are already widely documented elsewhere and will not be discussed here (see for example ESReDA, 2015; RoSPA, 2015). Suffice to note here that it is especially difficult for one to learn from failures of a technical nature, as one lacks the basic scientific know-how to be able to draw inferences from the experiences systematically, as well as the presence of complex systems that are inherently difficult to understand (Cannon & Edmondson, 2005). This may also be a reason why learning using simulations are not usually introduced until later years of study. Indeed, drawing on historical data, Mannan & Waldram (2014) noted that the international community of process engineers has not been good at learning lessons from their past accidents, and called for a paradigm shift in learning from failure.

This last point is also a poignant reminder of how students are trained: they are often given the information needed to “solve problems” during tutorials. Usually this involved them putting in the right numbers into the right equations (often already given), so that they can arrived at a certain pre-determined “answer”. Students do not question the reasonableness of their solutions. In doing so, we had inadvertently, “design-out” failures from the learning process.

This paper attempts to look at failures from a different perspective: that of learning from failure from the business world, entrepreneurship or the design-related education. More specifically, we look into ways to at “failure on purpose”, or what Sitkin (1996) termed “intelligent failure”. The latter arise from Sitkin’s observation that most organizations tend to try to engineer failures out of their processes, thus robbing themselves of the opportunity to identify weaknesses before small failures become big catastrophes. In fact, extant models were often designed for efficient and structured approaches that emphasize failure avoidance (Tawfik, et al, 2015). Another term often used is “failure-based learning” (Tawfik, et al, 2015). These terms are used interchangeably in this paper.

Learning from failure is often celebrated in the design world, to quote a famous saying by John C. Maxwell: "Fail early, fail often, but always fail forward”. Jackson, et al (2022) noted that failure is part-and-parcel of the design process: it is embedded in the design process. Iteration is an important attribute of design, and failure would seem to be an accepted, even expected, part of design and a learning opportunity. The benefits include: (a) Failure as a mechanism to uncover key concepts from students; and (b) Failure induces thoughtfulness in problem solving. To realize these benefits, students need to be aware of their failures. In other words, for failures to be a useful learning experience, students need to analyze failures, understand what happened, why it happened, and how to move forward.

This is especially important to students, who due to their lack of experience and hence lack of confidence, tend to be obsessed with "concreteness", for the "how to do", putting heavy emphasis on following procedures; thus limiting their interest exclusively to "the solutions". The proposed approach will refocus the attention to the strategic value of analysis and praxis; to connect to theories and make-sense of the data (Dominici, 2020).
A question may be posed whether learning from failure is a form of problem-based learning (PBL). To the best of the author's knowledge, the extant literature did not explored such relationship. To be sure, works on problem-based learning certainly highlighted the role of failure in promoting student learning, but more emphasis is placed on role of teacher in facilitating the learning process. An interesting work is one reported by Dobson, et al (2021) who mentioned the use of problem-based learning on the teaching of entrepreneurship and how learning from failures in business plans and models; but the focus in not on the connections between designing learning tasks that deliberately resulted in failure. There are obviously various discussions on PBL, and it is not the intent of this paper to discuss at length the method of engaging students in learning. Readers interested in the development of PBL, how it works and the challenges is posed can refer to the works of Servant-Miklos (2020). The remainder of this section briefly explains what problem-based learning is, and how does it compared with learning from failure.

Suffice for the purpose of this paper is the reference to the works of Hmelo-Silver (2004) who explains problem-based learning (PBL) as an instructional method in which students learn through facilitated problem solving. In PBL, student learning centres on a complex problem that does not have a single correct answer. Students work in collaborative groups to identify what they need to learn in order to solve a problem. They engage in self-directed learning (SDL) and then apply their new knowledge to the problem and reflect on what they learned and the effectiveness of the strategies employed. The teacher acts to facilitate the learning process rather than to provide knowledge. The goals of PBL include helping students develop: (1) flexible knowledge, (2) effective problem-solving skills, (3) SDL skills, (4) effective collaboration skills, and (5) intrinsic motivation.

Tawfik, et al (2015) on the hand, argue that existing "learning design often focus on templates of successful problem-solving to support students". They noted "theories from numerous domains suggest that failure is a fundamental aspect of the learning process" and that educators should make use of learning from failure to promote student learning. Educators should create "opportunities for learners to encounter and overcome failures during problem-solving as a way to refine extant mental models and promote conceptual change". Hence, from a problem-solving perspective, learning from failure can be viewed as a form of PBL. It too, aims at developing students' problem-solving skills. However, it is different from PBL in that – at least as far as chemical plant operation is concerned – there is often one correct solution to bring the chemical process from disturbance back to steady operation. Learning from failure in chemical plant operations requires that students search their prior knowledge to see connections between various process variables shown on dashboards with issues with the specific process operation on hand. SDL skills may not play a key role here, as the key step in tackling chemical process operational problems is to connect-the-dots among the many indicators (usually manifest themselves in the form of alarms). Hence the process technicians will first "dig deep" into his/her knowledge base to formulate plausible cause-and-effect relationships among the indicators, and where needed, able to identify what other data are needed to confirm or disprove a hypothesis.

Other than problem-solving skills, the goals of learning from failure in the context of chemical process operation from the perspective of this work is to help students develop: (1) sense-making skills, notably discerning the relationships between process variables, (2) ability to work under pressure, (3) resilience, (4) self-reflection, and (5) self-confidence in decision-making. These are the traits or dispositions that the author called “failure-tolerant” mindset. The next section explores in greater details how to develop the skills in seeing connections in chemical process operations.

LEARNING FROM FAILURE IN CHEMICAL PROCESS OPERATIONS: BACK TO BASICS

To this end, we need to review how we teach problem solving in chemical engineering. Failure in chemical processing industries can take several forms, starting with failure in design, which will create other operational problems later when the faulty design was adopted and implemented. An example of failure at the design stage is that an equipment was wrongly sized, or wrong materials of construction specified. The former may be due to the use of wrong equations or correlations, or using inappropriate properties of the mixtures being handled in the ensuing calculations. Failure at the operation stage may result directly from the fault at the design stage, but failure can also occur due to the plant not being operated correctly, for example, not following standard operating procedures. The type of failure of concern here is one that arise from abnormal operating conditions, for instance: (a) due to changes in properties of the mixture being handled; or presence of impurities in feed; (b) process upsets such as loss of heating or cooling; or damage to equipment (e.g. due to wear and tear).

Due to the large varieties in chemical plant operations, it is not possible nor desirable to teach students all the different chemical processes. It is also not practical to have simulation models that cover all aspects of chemical processing. What we can and should do, it to go back to basics: emphasising more on the chemical engineering principles and fundamentals. Two areas that we specifically wanted to focus on are:
(1) Relationship between process variables
(2) Visualization of chemical processes operations

A process variable in our context refer to a parameter in chemical processing plant that can changed and is often monitored so as to maintain it at a constant value. Examples of process variables include flow rate, temperature, pressure, composition. Chemical engineering as a discipline is unique in the sense that it deals with mixtures most of the time. Mixtures are substances that contain more than one components, and in the case of crude oil, there can be hundreds of components. Mixture properties are affected by the relative compositions of substances in the mix, and their interactions with one another. Often the chemical processes take place under high pressure and temperature, in enclosed containers made of carbon steel or stainless steel. Hence, the contents are not visible. Changes in plant operating temperatures and pressures can affect the mixture compositions and their distribution between the phases (typically between gaseous and liquid phases) which in turn also affect mixture properties, and hence product specifications.

Learning from Failure: Understand the Relationship between Process Variables

Being able to identify the relationships between various variables is useful in helping to make sense of the myriad of information that came through the many sensors in a typical chemical plant and displayed on performance dashboards. Being able to visualize the chemical processes enable one to explore via the mind’s eyes, potential hazards of a proposed course of action, especially when responding to an emergency in a chemical plant.

This aspect of learning is often neglected. The author opined that this is often the result from the current dominant approach to teaching, where different engineering fundamentals (e.g. fluid flow, heat transfer, process safety, etc) are often taught in separate modules, resulting in compartmentalized learning. In addition, the tendency of faculty to focus on such problem solving within one's own module often means that the focus is on applying the correct equations; whereas the needs to ensure that the correct data are used is often neglected.

Developing students' ability to see connections between various process variables also helped them to integrate knowledge acquired in different chemical engineering core modules, taught separately. We found that our students often do not know how to make use of what they had learnt in one module and connect them to another module. We termed this the challenge of "Unknown Known" as shown in Figure 1, in the lower left quadrant. This figure is our interpretation of the Rumsfeld Matrix, named after Donald Rumsfeld the late former U.S. Secretary of Defence, who stated in his February 2002 Defence Department briefing: "*There are known knowns. There are things we know that we know. There are known unknowns. That is to say, there are things that we now know we don't know. But there are also unknown unknowns. There are things we do not know we don't know*." (Logan, 2009).

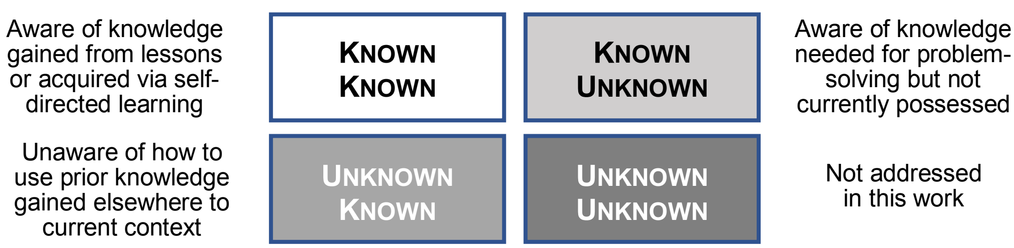

Figure 1. Rumsfeld's Matrix adapted to Student Learning

Focusing on helping students making connections between the modules they learnt is therefore the focus on our approach to teaching the "fundamentals of fundamentals". More specifically the emphasis is to get students to be aware of their "unknown knowns". This will start with understanding the relationship between process variables, by recognizing how a change in the process operating condition(s) will affect other process variables. This can be covered in Year 1 in modules such as *Laboratory & Process Skills 1* (in Semester 1) and *Laboratory & Process Skills 2* (in Semester 2). Then in Year 2, more connections can be made between the "unknown knowns" in terms of basic equipment covered in Year 1 Semester 2 (in modules such as *Heat Transfer & Equipment*), and more sophisticated ones in Year 2 Semester 1 (such as distillation in *Separation Processes*; chemical reactors in *Chemical Reaction Engineering*). Deeper relationships between process variables and these equipment can be further explored in modules such as *Process Operation Skills 1* (in Year 2 Semester 1) and *Process Operation Skills 2* (in Year 2 Semester 2).

Suitable integrated learning experiences can be designed for these modules to change students' mindset about failure in a progressive manner; by deliberately "build in" various aspects of failure in chemical plant operations. This is shown in Figure 2 where students will first understanding the consequences resulting from failure. Then, they will learn to identify signs of potential problem areas by overcoming their blind spots in the "unknown knowns"; conduct inquiries into causes and sources of failures; and gradually learn to embrace failure as a source of learning. They will gradually develop the requisite confidence to achieve a sense of mastery in dealing with problems in chemical plant operations.

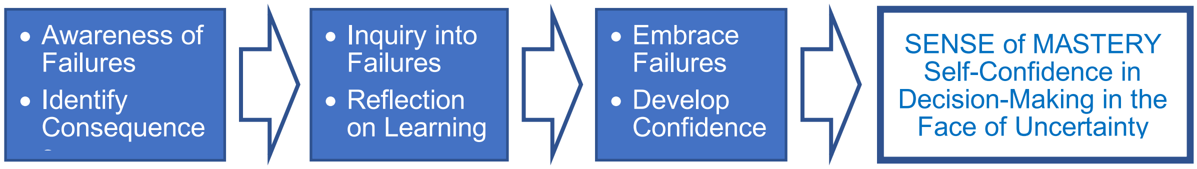

Figure 2. Pedagogy for Learning from Failure

The next section explores in details how we can use the CDIO Framework to guide us in the design of learning tasks using failure-based learning.

CDIO FRAMEWORK TO SUPPORT LEARNING FROM FAILURE

The CDIO Framework lends itself naturally to provide guidance to develop students' capacity to learn from failure. Essentially, we make use of the following 3 guidance questions:
1. Need: What is the professional role and practical context of the profession?
2. Learning outcomes: What knowledge, skills and attitudes should students (and adult learners) possess as they graduate from our programs, and at what level of proficiency?
3. Curriculum, workspace, teaching, learning and assessment: How can we do better at ensuring that students and adult learners learn these skills?

The CDIO Syllabus provide key learning outcomes of the skills and attitudes needed to support learning from failure, for example:

2.3.4 Trade-offs, Synergies, Judgment and Balance in Resolution
2.4.1 Demonstrate Positive Attitude and Willingness to Make Decisions in Face of Uncertainty
2.4.2 Perseverance, Urgency and Will to Deliver
2.4.6 Self-Awareness, Self-Reflection, Metacognition and Knowledge Integration
4.1.2 Address the Impact of Engineering on Society and the Environment

These skills and attitudes can build on abilities already covered in existing modules, such as of growth mindset, intrinsic motivation, teamwork and communications, critical thinking and problem-solving. The extant literature also provide guidance on strategies that can be used to include learning from failure in students' experience. A good reference is provided by Tewfik, et al (2015) as shown in Table 1; which supports the pedagogy detailed in Figure 2.

Table 1. Instructional Design Principles for Failure-based Learning (Tawfik, et al, 2015)

Guidelines	Examples of Strategies
1. Allow learners to identify failure	
Define conditions for failure	Learners should be prompted to address the conditions for success and failure before problem-solving. Otherwise, they may not be primed to investigate failure-states
Identify failure perspectives	Learners should be given the opportunity to redefine the success and failure from an alternative perspective after the initial parameters for failure are constructed to promote cognitive flexibility
2. Design learning environments to intentionally encounter failure	
Failure-based question prompts	Question prompts designed for students to discuss and/or encounter failures students might otherwise overlook

	Generate failure-based causal models	Learners could be asked to explicitly generate a causal model that may result in a failed solution from a specific perspective or lens
	Models of failure	Case libraries could be provided as a series of failure-based narratives that learners could access as just-in-time resources
3.	Support inquiry into failure for analogical transfer	
	Inquiry and hypothesis generation	Prompts the learner to reflect on their experience and misconceptions Learners can be asked to generate and justify reasons for the fault-states and breakdowns in causal reasoning
	Reflection on failure	Question prompts embedded to encourage learners to reflect on individual introspection; artefacts of the failure context; and systemic perspective of the failure
	Identify opportunities for transfer	Space to manipulation variables or parameters so that learners are able to demarcate the appropriate conditions for transfer
4.	Support solution generation to resolve failures	
		Space or prompts provided within a learning environment to help students generate, debate, select, apply, and evaluate solutions to resolve root causes to breakdowns of the micro-failures

The strategies presented in Table 1 can easily fit into the generic descriptors of appropriate CDIO core standards. They serve to illustrate specific examples of how the CDIO Standards can be interpreted when applied to promote learning failures. This is shown in Table 2.

Table 2. Selected CDIO Core Standards to Guide Designing for Learning from Failure

No.	Standard Name	Guidance to Designing for Learning from Failure
1	The Context	Describe possible workplace scenarios, focusing on work items that opportunities to introduce elements of failure that promotes learning, either from mistakes made, or in anticipating probable failures; and come up with plausible solution(s).
2	Learning Outcomes	Key skills and attitudes need to develop capacity to learn from failure, as per CDIO Syllabus; which also serve as expectations that will be clearly communicated to students.
3	Integrated Curriculum	Provide guidance on how to sequence, in suitable modules, lessons that promote learning from failure in a progressive manner, from initial exposure to failure, perspective on failures, and its eventual acceptance in a positive light; i.e. towards the gradual shift in mindset towards embracing failure. Such sequence will build on prior knowledge, skills and attitudes already integrated.
7	Integrated Learning Experiences	Simulated real-world work environments will need to be designed to provide students with various opportunities to experience failure in assigned tasks and repeated practice. Opportunities to transfer from one context to another will be enthusiastically explored.
8	Active Learning	Flipped learning will be leveraged upon to engage students in the in-class components to stimulate critical thinking, such as discussing about the causal model(s) of failures.
9	Enhance of Faculty Competence	Faculty need to be trained as facilitators, with strong interpersonal skills to encourage open-mindedness in students, to support learning from failures alongside the technical module one is teaching.
10	Enhance of Faculty Teaching Competence	Faculty need to be familiar with pedagogy presented in this paper, and trained to design integrated learning experiences with experiential learning to scaffold students' development of positive outlook towards learning from failure.

11	Learning Assessment	Approaches to evaluate reliably the progressive development of failure-tolerant mindset will need to be formulated; and sufficient time devoted to giving students feedback to improve learning. Reflection on failure will be a key component to support development of failure-tolerant mindset.
12	Program Evaluation	Review the integration effort to identify areas of improvement as part of the module review process in SP Academic Quality Management System.

Table 3 provides some examples of how learning tasks will progressively develop various aspects of competency needed to learn from failure over the 4 semesters of study, to better prepare them to handle operations of chemical plants when they join the workforce as process technicians upon graduation. Specific teaching and learning practices will be developed for each stage of study using the guidance from Table 2. It is expected that by Year 3, students are comfortable at encountering failures in process plant operations, fully understand the consequences of failures, will strive to operate chemical plants safely to avoid any catastrophic failures.

Table 3. Learning Tasks to Promote Progressive Development in Learning from Failure

Year 1 Semester 1	Year 1 Semester 2	Year 2 Semester 1	Year 2 Semester 2
Overall approach: Leverage on current effort in instilling growth mindset in students, to get them familiar with handling big data; promote understanding of relationship between process variables via appropriate data visualizations; to support various stage of development for learning from failure.			
Develop competency in Data Fluency: from handling of big data to their visualization to aid identifying relationship between process variables			
Refine current learning task to include selecting and interpreting large data set from literature (often in tabular format to discern possible relationships between various properties of a mixture.	Create basic-level data visualization to display appropriate process variables to identify potential issue in a small-scale pilot plant. Explain potential consequences if safety is compromised.	Create more complex data visualization using more process variables based on moderately complex pilot plants, but still limited to operations within the same single piece of equipment.	Create complex data visualization using more process variables based on complex pilot plants. This can now be across several plant items in the same process unit, or even across process units.
Develop competency in preparing and/or using Experimental/Operating Procedures: visualization of steps involved and consequences of not adhering to procedures			
Develop procedures for some experiments, based on resources provided. Visualize ways in which an experiment is to be conducted based on the procedures prepared, and identify potential safety hazards.	Identify mistakes in a given set of standard operating procedures that was deliberately arranged in wrong order that may result in undesired or negative consequences (via visualization); and to correct these mistakes.	Operate moderately complex pilot plants; explain rationale for prescribed sequence in operating procedures; identify potential process safety hazards and consequences if deviate from operating procedures.	Use dynamic simulation and/or digital twin to investigate different outcomes if deviate from prescribed set of operating procedures for complex pilot plants (available as digital models only; not physical items).
Develop competency in explaining relationships between process variables during chemical plant operations; and potential consequences			

Conduct experiments, observe and identify possible sources of errors; explicitly record all observations; visualize possible conditions that can lead to failure; and identify areas of improvement.	Operate simple pilot plants, identify potential hazard during plant operation; leverage on vendor mistakes in the plants (left uncorrected to provide learning opportunities, so long as safety is not being compromised).	Operate moderately complex pilot plants; identify potential hazards; identify potential impact of mal-function in one plant item on other plant items within the same process unit, and explain the reasons.	Operate relatively complex virtual pilot plants (digital twin and/ or dynamic simulation), explain using observed process variables the causes of various simulated scenarios where failure in encountered.
For tracking of students' development of change in attitude towards failure, we will use focus group discussions, along with surveys administered alongside existing initiative on teamwork development. Reflection journals will be used: at different stages of study, students are to document their learnings and changes in perceptions regarding failures and coping with the changes.			

There are other aspects of chemical engineering education where benefits of learning from failure can be realized. One ideas presented earlier represent one main pathway of competency development: that of process plant operation to prepare students to work in the chemical processing industries. The DCHE curriculum had another pathway of chemical product design that equip students with the competency of using chemical engineering sciences and principles to design, conceive, implement and operate chemical products, systems or services. This is another area rich in opportunities to introduce deliberate failure into students' learning, especially via the "project spine" in the DCHE curriculum (Cheah, 2021). This area is part of a wider research topic the author is involved in a project with the Singapore University of Technology and Design (SUTD) and will be the topic of a separate discussion not covered in this paper.

MOVING AHEAD: DEVELOP A "LEARNING FROM FAILURE" MINDSET

The Industry 4.0 revolution will cause significant effects, such as the new occupations and job profiles, changes to employment forms and a more important role for the platform economy, generating challenges for social policy. The development of human capital and consumer behaviour will be impacted. The educational profile of the human capital is necessarily changing and new approaches to education systems must be introduced (Gajek, et al, 2022).

This paper had discussed how learning from failure can be implemented in a chemical engineering curriculum, specifically focusing on chemical process operations. The approach suggested in the paper is to first focus on connecting the dots among the many process variables in a typical chemical plant, so that they can discern how these process variables are related and interacted with one another. This, coupled with domain knowledge of how the chemical processing plant works, will better equip students to perform as process technicians in the chemical plants; that they are able to make-sense of the plethora of data that come through the plant dashboard, analyse any output from the plant AI system; in particular during process upset.

We hope to prepare a new breed of graduates who have the technical competency and mental capacity to visualize potential failures, to benefit from ability to anticipate such failures, and take corrective measures to prevent them from happening. In this way, we hope that our graduates will have the self-confidence to make decisions in face of uncertainly in a digitalized chemical industry enabled with various AI tools that support plant operations.

Much remains to be done, to develop the learning tasks as suggested in Table 3. Fellow colleagues will need be engaged to buy into this new approach of training – will be a challenging feat in view of today's workload for academic staff! They have to make to existing learning tasks or design new ones. We also need to monitor students' learning progress from Year 1 to Year 3, for example via a longitudinal study involving questionnaire surveys, focus group discussions, interviews, etc.

To this end, we also need to better prepare our lecturers to engage students differently, especially in allaying students' fear of failure in the 'academic sense', i.e. resulting in poor grades. We will be exploring various professional development workshops, for example with SUTD. A working group on learning from failure had been proposed and accepted for this International CDIO Conference, and we welcome like-minded CDIO collaborators to work with us on this aspect.

CONCLUSION

This paper shares an approach based on the CDIO Framework that enabled learnings from failures in the chemical engineering curriculum, focusing specifically on chemical plant operations. The aim is to better prepare graduates to meet the workplace demand equipped with sound technical knowledge to make informed decisions in face of challenges, particularly those of time-sensitive manner. A complete pedagogical approach had been presented taking into considerations extant literature about learning from failure; and an alternative way of training students grounded in the principles from the CDIO Framework is offered.

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INQUIRY, THE SCIENTIFIC TOOL FOR ALL INSTRUCTIONAL METHODOLOGIES

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ABSTRACT

The Inquiry based learning, in the class of active learning is receiving lot of attention these days to an extent that, it is a major theme in national science education reforms: "Science education for All in America". Hence an attempt is made in this study to measure the effectiveness of inquiry-based learning in the field of engineering specially applied to Microprocessors and Microcontrollers course. Jubin simulator was used as an ICT tool for implementation. This paper discusses the process by which the inquiry questions are designed. These questions along with the carefully defined procedure helped the students to do self-discovery of the concept called stack, which is associated with all programming. Results showed that inquiry is positively linked with outcomes when it integrates teacher guidance, and negatively when the inquiry is not designed effectively. It also shows that optimal learning is achieved when technology is blended with systematically designed inquiry learning instructional methodology.

KEYWORDS

Inquiry, simulator, Stack, Standards: 2, 5, 6, 7, 8

INTRODUCTION

Project is an important instrument to evaluate students to examine if they have developed critical thinking skills for their career success. When students do their project, if something fails, they should question themselves. There is some evidence regarding the Generation Z students that, they generally lacking in critical thinking skills as they spend most of their time in gadgets (Mancall-Bitel, 2019) and have no time to reckon with. Now and then simple position change makes their project working, but the students will not have any clue, why it worked and do not want to dig too deep. Such students certainly need inquiry questions by the teacher to drive them towards learning from their day one. Inquiry may be referred to as a technique that encourages students to discover or construct information by themselves instead of having teachers directly reveal the information (Uno, 1999). However, making inquiry questions is an art, it needs exceptionally competent teacher to design. This paper presents the process by which the given inquiry learning is designed to understand the concept of stack in Microprocessor and microcontrollers course. This paper has been divided into five parts, where the second part reviews relevant background on active learning, Inquiry Based Learning (IBL), Process Oriented Guided Inquiry Learning (POGIL) and compares them to other forms of active learning. Third part explains the development of inquiry questions with an example both for conceptual level understanding and higher cognition level in the bloom's taxonomy. The section 4 relates the work to CDIO standard, and the last part analyses the feedback received by the students and discusses the results.

LITERATURE REVIEW

Active learning is a technique of teaching in which students actively engage with course material through conversations, problem solving, case studies, role plays, and other ways. Compared to passive methods like lectures, active learning approaches lay more responsibility on the learner, although in an active learning setting, instructor direction is still essential. Activities that promote active learning can last for a few minutes, an entire class period, or even several class periods (Felder & Brent, 2009). Among all active learning techniques collaborative learning (Hiltz, 1988). Concept mapping (Davies, 2011), scavenger hunt (Stark, Opuda, McElfresh, & Kauffroath, 2021), Role playing (M.D., 2009), Jigsaw technique (Adams, 2013) online discussion boards (Covelli, 2017), flipped classroom (Tucker, 2012), inquiry learning (Pedaste, et al., 2015), inquiry plays a special role as it leads the learners to construct the knowledge themselves, instead of having teachers directly reveal the information. Construction comes from the guided questions from instructor or unguided questions from students. The keystone for the construction of such knowledge comes from the answers to such questions. However, the method used to construct the keystones depend on the constructor of the questions (Reiff, Harwood, & Phillipson, 2002). This infers that the volume and type of knowledge that can be constructed in an engineering inquiry classroom would depend on the questioning skills of science teachers. Hence the methodology starts with the way to frame such questions, which makes them to retain the knowledge they earned for long time.

Independent learners will be more driven to find solutions to the most difficult problems encountered by an organisation or group since they are aware that knowledge acquisition never stops. Students actively participate in their own learning process in an inquiry-led learning style. In the end, this results in a feeling of independence that motivates pupils to keep asking questions and looking for solutions long after class has ended (Hwang & Chang, 2011). IBL is generally classified into 4 types which are (i) The Structured Inquiry Approach, (ii) The Open-Ended Inquiry Approach, (iii) The Problem-Based Inquiry Approach and (iv) The Guided Inquiry Approach. A good inquiry-based instruction should not only develop conceptual understanding, but also more mature epistemic beliefs (Nitsche, Mathis, & O'Neill, 2022) and one such beliefs include, that knowledge is based on empirical evidence whose meaning is influenced by the models/theories which scientists employ (Pluta, Chinn, & Duncan, 2011).

IBL encourages students to think critically and analytically. While analytical thinking assisted students to establish the similarities and differences in variables and tendencies in data, critical thinking aided them in determining the reason why a variable changed and how that change affected other variables. Also, (Duran & Dökme, 2016), demonstrated that IBL, leads to lifelong learning by focusing on making the students to ask questions, critical thinkers, and problem solvers. POGIL also works in a similar way except for group setting with different roles assigned to each student (N.M.Masoodhu Banu, 2017) where students help each other. The role of the teacher as a facilitator within the model of inquiry as opposed to a more traditional didactic teaching approach (Dana, Thomas, & Boynton, 2011) contributed to students' active engagement in all the inquiry classroom settings. Some learners learn better with experimental setting and the authors (Zannin, Lima, & Pinto, 2021) have combined the inquiry learning with the remote lab settings, however this lacked instructor's direct interaction. Also, all the literature mainly delas with the design for inferences rather than instructional design methodology. Hence, this paper attempts to syndicate the benefit of practice-oriented learning and guided inquiry learning for optimal learning along with microlevel instructional design.

METHODOLOGY

The study employed a controlled design in which half the participants went through normal lecture classes with clear diagrammatic representation of the topic being addressed as well as explanation through simulation. The other half (experimental group) went through the same simulation activity performed by students in group with IBL to construct the concept themselves. The activity for the teacher is to develop a worksheet and design a list of outcome questions which will be able to evaluate engineering skills sets attained by the students. The activity of the student is to record the observations (all general registers value) and the stack pointer and program counter in specific to understand the program flow. They also must answer the questions listed in the outcomes. The number of questions answered by the students were used as performance index, which indirectly measures their capability as a reflective thinking person. The learning material (worksheet) that is implemented in this research have passed the validity test by presenting and testing it with the other teachers. As teachers play the most influential role in inquiry learning (Grandy & Duschl, 2007), some beginning teachers were also included in this study, but to evaluate their skills in designing the inquiry question. i.e., after they were taught to answer the worksheet designed by senior teachers, they were asked to design such inquiry worksheets for some other concepts and the outcome was evaluated with the same set of students.

DESIGN

The students of Biomedical Engineering department were considered for this research. Generally, they have an idea that programming is not required for Biomedical Engineers. Hence it is basic requirement for the teachers to kindle interest in learning by making the learning process easy such that it retains in their memory for long time. The research uses simulator-based approach as it is difficult to use the development board on daily basis. Jubin simulator (an open-source simulator) for 8085 microprocessor was chosen for this. First an appropriate code snippet was designed for explaining the concept of stack. Then a clear step by step process has been developed to design inquiry questions. These questions along with step-by-step operation of Jubin simulator was given to students to self-discover the concept of stack. The whole process will be like guided investigation.

The students were allowed to choose their mates or remain them as individual as the core point of this research is to kindle their thought process and not cooperative learning.

1. Teachers develop questions in such a way that students get curiosity to answer.
2. Supplement the questions with some action, may be to read a journal paper or book chapter with pointers to read particular section. More than this if it can be supplemented with step-by-step procedure simulation activity, the inquiry kindles the curiosity for learning. In class activity is best mode as, students' needs the access to the faculty. Students will have to construct after the end of this class. Sufficient time needs to be given for such activity
3. Check everyone's construction for meaningfulness. If found to be valid, make the students present what they've learned as communicating what they understood is better than just understanding for themselves.
4. Request students to reflect on how the inquiry questions given by the teacher worked on and what did not. Reflection is key as it gives the faculty a guidance to correct them if majority could not understand the concept by the whole process. Metacognition—thinking about thinking can work this way. Also, this makes the students focus on how they learned in addition to what they learned. This makes the students create questions themselves for understanding factual concepts.

Instance

The students of 2nd year Biomedical Engineering were considered for the activity and the course considered was Microprocessor and Microcontrollers. Total 60 students were considered, where 30 of them put in control group and the rest 30 in experimental group. Though many of the concepts were taught with simulator, the concept of PUSH and POP were taught with inquiry learning. In case of simulator-based learning, the teacher executed every step and asked the students what happened at each point, but with the guidance of asking them to look at memory or registers appropriately. Though they understood at that point of time, they did not apply in general for all the concepts taught later. Hence it is decided to have an IBL to make them to think themselves to arrive at the answers to construct the knowledge. The following inquiry questions were framed as in Table 1 to focus the student's attention to one key topic called stack.

Port programming with SP and PUSH POP concept

1. Start the debugging session.
2. Observe the stack pointer value before execution and make note of it
3. Open memory window I: observed SP value
4. After executing each line record your observation in the table 1 with columns titled registers and stack pointer

Table 1 Guided Inquiry questions for the given code snippet

S.No	Programming step	Observation	Value at Stack pointer and program counter	Value at the stack pointer memory
1	Execute the first three instructions one by one and note the Accumulator and other register values			
2	After the execution of first three instruction. Note the value of stack pointer here			
3	Observe the value of PC after the CALL instruction, note the value of stack pointer too			
4	After each PUSH, POP instruction, observe the changes in SP and its contents			
5	What is the operation taking place up to STA C053			
6	With 2 POP instructions, what happens to SP and its contents			
7	After RET instruction where the program jumps to?			
8	What was the function done by the CALL subroutine?			

CDIO CONNECTIONS

Learning outcomes are mandatory for any courses designed in the curricula. Similarly, each concept explained also should have its own learning outcomes and are listed in Table 2. CDIO Syllabus lists various outcomes like disciplinary, interpersonal and system/product building skills. The learning outcomes acquired through IBL and hence disciplinary skills as discussed in the CDIO standards are listed in the below Table 3. Though the present work IBL does not relate to the design experience directly, the skill set acquired will help the learners in future when they design an embedded system. Embedded systems need compact memory and hence the most appropriate value for the stack size needs to be designed. Since the students know how PUSH/POP affects, they will design their system with care. If any issues come after their design during prototype development, they have solid analytical knowledge about the concept stack and hence they will have rich design and

Table 2 Questions on Learning outcomes

S.No	Outcome Questions
1	What did you learn about PUSH and POP From where to where the content is pushed. from where to where the content is popped Is there any order in which you need to do PUSH, POP operation?
2	What does CALL instruction do? What happens to PC and what happens to SP?
3	What does RET do? What happens to PC and SP?
4	Change the order of POP instructions and observe what happens to the add instruction results now? So justify if we can interchange POP Ing and PUSH ing order?
5	How the stack pointer changes with respect to each PUSH and POP instruction
6	Summarize the entire process with respect to CALL instruction

Table 1 Disciplinary skill set addressed according to CDIO Syllabus.

S.No	Outcome/Competency Questions	Skills acquired and CDIO syllabus outcomes
1	What did you learn about PUSH and POP From where to where the content is pushed. from where to where the content is popped Is there any order in which you need to do PUSH, POP operation?	Engineering reasoning and problem solving (2.1)
2	What does CALL instruction do? What happens to PC and what happens to SP?	Curiosity 2.4.6
3	What does RET do? What happens to PC and SP? What is the difference you observed between CALL and RET	Critical thinking 2.4.4
5	Relate all the above facts to arrive at how the stack works. What can be the programming mistakes?	Thinking holistically (2.3.1)

implement experience. (CDIO Standard 5 Design-Implement Experiences.) The study also addresses the Standard 6 (engineering workspace), because without such a space, a hands-on learning leading to self-discovery of knowledge would not be possible. The Standard 7 (Integrated Learning Experiences) is also addressed due to the nature of the model i.e., inquiry learning unsurprisingly experiences the students through interpersonal skills by way of discussion. Finally, as, Inquiry learning gives no scope for passive learning, it can be said that, the proposed work also addresses Standard 8 (Active Learning)

RESULTS AND DISCUSSIONS

Through this research, guided IBL material was developed and implemented to improve student's engineering programming skills in terms of attention to details, thinking and retaining information. Assessment is needed in some form to validate the work and hence the questions were classified for all the three skills mentioned above. Table 1 questions were mapped to skill set 1, and Table 2 questions were mapped to skill set 2. After the inquiry class questions related PUSH, POP operations in general, the application of it for other scenarios were given. This was used to assess their knowledge application and, hence retaining information. Hence the response of every individual student for the above worksheet was evaluated. The evaluation results are given in Table 4. In both groups almost 90 % of the students answered them correctly for Table 1 questions. However, for table 2 questions, 90 % response from experimental group and only 55% response from the control group. This is due to the instructional delivery difference. Teaching the concept of stack using passive lectures takes less time in comparison. However, delivering the content through such inquiry worksheet makes them pay attention also to other details. Before they learn instructions like mov, mvi etc and then forget. But here the learning is carried forward in the process of understanding the stack concept and the repetition in learning leads to improved retention of the knowledge. However, in teacher led delivery it is not so, as they grab only the comprehension i.e., stack increases or decreases by 2 or 1 byte. This helps the students to extend their thinking from the concrete and factual to the analytical.

Table 2 Evaluation Results

S.No	Item	Experimental/ treatment group		Control group	
		In numbers	In percentage	In Numbers	In percentage
1	No of students answered questions in Table 1	27	90	27	90
2	No of students answered questions answered both in Table 1 and Table 2 except question number 6	27	90	16	55
3	No of students answered all the questions in table 1 and table 2	21	70	9	30
4	No of students just operated/not operated the Jubin Sim	3	10	3	10

Unless they think, they could not construct the concept. It can be seen from the Table 4 results in row 3 that, while 70 % of the students from experimental group (IBL) were able to construct the knowledge about stack pointers, only 30 % of the students from the control group could do the same. The inquiry worksheet blended with technology paved the way for the experimental group to construct the concept themselves. This ability of self-constructing the knowledge is one of the prerequisites for making oneself dependable expertise. Not only that, but it also teaches the types of programming mistakes and hence the consequences. Students self-trial in changing the order of PUSH and POP and hence the answer to the 4th question in Table 2 addresses such mistakes. When the same concept was taught for the microcontroller 8051, students immediately captured and could solve many problems given in the class. Thus, the designed activity avoids student's mentality of understanding the concept only with words and sentences and limiting the concept only to the specific field. If concept construction comes through their own self, through such learning, students will realize the importance of the concept they learnt, like stack in this research, and will be able to apply to other applications, like embedded system project implementation. The retention of the knowledge to apply whenever needed can be related to long time memory.

Evaluation of the student's worksheet showed that there were three kinds of learners. Though the questions had one clear answer some did wrong because they were not knowing the operation of the tool sincerely. They lacked interest and hence no motivation to learn. Such kind of learners need counselling for motivation. The next group answered the observatory questions clearly, but not able to answer the learning outcome questions. The reason is that the concept of knowledge construction through appropriate thought process, needs some reasoning ability to connect the dots to get the result. The third group did well in all respect. Even though the second group did not answer the outcome questions, latter they were able to grab the concept by repeatedly giving new problems on the same context, i.e., they could convert their factual knowledge to analytical knowledge over the period. Overall, the reflection is in experimental group, 90% of the students could identify the operation of stack, while programming and its usage. and answered all the inquiry questions (row 2, evaluation results in table 4) what they observed in the simulator but some from the 90% (row 3, evaluation results in table 4) could not construct the concept by linking all together, though indirect linking questions were also given. The remaining 10 % students could not even operate the simulator either because they do not have interest, or they did not understand. Their attention in the classes and their involvement showed that they did not have interest to learn.

However, the success of inquiry-based instruction lies hugely with teacher's perception motivation and above all competency in creating such questions. Hence teachers were asked to prepare inquiry questions with same simulator for teaching other concepts like differentiating between return from interrupt and return from subroutine. 75 % of the young faculty were not able to design the code fragment for teaching this concept. They knew to use the technology i.e., the simulator here and can search and teach an example for subroutine and interrupt. But could not apply their knowledge in designing an appropriate small piece of code for teaching the same. When the same set of students were involved to evaluate beginning teacher's worksheet, meaningful knowledge construction did not come. This is because they did not find linking questions to provide meaningful reflection or knowledge construction. Hence it is concluded that, not only competency but also a skill set of integrating the technology with the content is essential for IBL. Also, the same topic was delivered without the simulator, but with IBL(framing of question was done differently), the generation Z learners did not find It quite interesting and focussed learning was not possible. It was found that, only 50% of the students could connect the dots to arrive at the solution. This gives clear evidence that learning is maximized when technology is integrated with IBL

CONCLUSION

This study attempted to evaluate the practicality of integrating the technology with the inquiry learning. The study results show that, IBL improves the skill set like attention to details, reasoning, and memory retention. However, it comes with the cost in the form of additional effort by the teacher, i.e., it is efficient only when proper content in the form of questions is integrated with technology. And the content creation needs interest along with time and competency of the faculty. The study results also show that, blending technology with inquiry learning leads better learning than without technology.

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BIOGRAPHICAL INFORMATION

N. M. Masoodhu Banu, Ph.D, graduated from Thiagarajar College of Engineering Madurai, obtained her M.E from College of Engineering Guindy, Chennai and doctorate from Anna University Chennai. She has worked in Indian Space Research Organization Bangalore, India from 1999 to 2000 and in Motorola India Electronics Ltd Bangalore from 2000 to 2008. During her tenure in Motorola, she has worked on audio and video codecs implementation on Texas processor and also on various real time operating systems, based system implementation, where all these algorithms went into various versions of Motorola mobile. Being an Industry person, knows the gap between Engineering Education standard and Industry requirement. Hence currently she has started focusing her scholarly activities on innovative pedagogy and curriculum development. She is a creative thinker in designing instructional methodology to suit the current generation student's needs. A highly passionate, hardworking teacher who wants to teach the students in multiple dimensions. Hence a lifelong learner who keeps updating with current technology and follow this to the core. She believes in the research which goes hand in hand with academics. Her research interest spans across Embedded signal processing, Artificial intelligence and neural networks et in addition to pedagogy.

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TRAINING FUTURE SKILLS - SUSTAINABILITY, INTERCULTURALITY & INNOVATION IN A DIGITAL DESIGN THINKING FORMAT

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ABSTRACT

The complex questions of today for a world of tomorrow are characterized by their global impact. Solutions must therefore not only be sustainable in the sense of the three pillars of sustainability (economic, environmental, and social) but must also function globally. This goes hand in hand with the need for intercultural acceptance of developed services and products. To achieve this, engineers, as the problem solvers of the future, must be able to work in intercultural teams on appropriate solutions, and be sensitive to intercultural perspectives. To equip the engineers of the future with the so-called future skills, teaching concepts are needed in which students can acquire these methods and competencies in application-oriented formats. The presented course "Applying Design Thinking - Sustainability, Innovation and Interculturality" was developed to teach future skills from the competency areas Digital Key Competencies, Classical Competencies and Transformative Competencies. The CDIO Standard 3.0, in particular the standards 5, 6, 7 and 8, was used as a guideline. The course aims to prepare engineering students from different disciplines and cultures for their future work in an international environment by combining a digital teaching format with an interdisciplinary, transdisciplinary and intercultural setting for solving sustainability challenges. The innovative moment lies in the digital application of design thinking and the inclusion of intercultural as well as trans- and interdisciplinary perspectives in innovation development processes. In this paper, the concept of the course will be presented in detail and the particularities of a digital implementation of design thinking will be addressed. Subsequently, the potentials and challenges will be reflected and practical advice for integrating design thinking in engineering education will be given.

KEYWORDS

Design Thinking, Sustainability, Future Skills, Interculturality, Interdisciplinarity, Transdisciplinarity, Standards: 5, 6, 7, 8

INTRODUCTION AND BACKGROUND

United Nations Brundtland Commission defined in 1987 one of the most cited definitions of sustainability: "[…] meeting the needs of the present without compromising the ability of future generations to meet their own needs." (United Nations, 1987, p.15). Considering today's consumer habits (e.g., Umweltbundesamt, 2022), it becomes clear that to achieve this goal, social transformations are needed so that today's generation can assume its responsibility towards future generations. Engineers will play a central role in these social transformation processes as they are significantly involved in the development of solutions for more sustainable production processes or products, for example (UNESCO, 2021; Magnell et al. 2022). Consequently, engineering students will be confronted with diverse requirements. These requirements can be divided into two levels, one related to engineering working content and the other to the working environment. From a content perspective there is an increasing need for a continuous reflection of the sustainable development goals (SDGs) (United Nations, n.d.; Lupi et al., 2022) in one's own activities, the question of sustainability in engineering processes and solutions (e.g., Brent & Labuschagne, 2004; Burke & Gaughran, 2007), but also the global applicability of solutions and products in a networked world (Konar et al., 2016). In practical implementation, this means, for example, the reflection of social diversity in innovation development, the reflection of different (cultural) perspectives on innovations and the consideration of the sustainability issue on the ecological, economic, and social level (Morandín-Ahuerma et al., 2019) already in development processes (Steuer-Dankert & Leicht-Scholten, 2016; Thürer et al., 2018; Fenner & Morgan, 2021). In addition to a stronger substantive focus on sustainability issues in engineering (Thürer et al., 2018; Sánchez-Carracedo et al., 2019; Lupi et al. 2022), engineers of the future will face an ever-changing work environment. Consequently, from a working environment perspective, changes due to an increasing digitalization, the world of work 4.0 and the disruptive transformation of industries and business models (Regnet, 2020; Albrecht, 2020; Mertens et al., 2022) can be mentioned as developments having an impact on the way engineers will work in the future. The digital transformation in companies (Teichmann & Hüning, 2018; Petry, 2019), new concepts of leadership styles such as digital leadership (Eggers & Hollmann, 2018), but also globalization and the associated need for (digital) collaboration in intercultural teams (Fajen, 2017), are examples of this.

Within the framework of their studies, engineers of the future must be prepared for these challenges in the best possible way to be able to meet them and fulfill the generational responsibility formulated by the United Nations (1987) and the UNESCO (2021). Consequently, the changed demands, both in terms of content and work organization, require an adaptation of curricular content in the context of engineering training. The CDIO Standards 3.0 as well as the CDIO Syllabus 3.0 represent initiatives, promoting the necessity of establishing sustainable development as central topic and giving with the CDIO Standard an optional advice for objectives and guidance (Malmqvist et al., 2020 a & b; Rosén et al., 2021; Malmqvist et al., 2022). In addition to the development to new standards and educational reforms (CDIO, n.d.), the discussion of the so-called *future skills* shows, that there is a need for competency-based teaching aiming to prepare students for the demands of tomorrow's world. In addition to the so-called technical engineering content, the teaching of these future skills is therefore becoming increasingly important.

As a central joint initiative of companies and foundations in Germany that provides holistic advice in the areas of education, science and innovation, the Stifterverband is a trend-setter in terms of studies that investigate future competencies. In collaboration with McKinsey, the German Stifterverband has identified which competencies will be of great importance in the future and has compiled 21 competencies for a changing world (Stifterverband & McKinsey, 2021). The 21 competencies have been broken down into four key competency areas:

1. Technological competencies (e.g., data analytics & AI, user-centered design),
2. Digital key competencies (e.g., digital ethics, agile working, digital collaboration),
3. Classical competencies (e.g., problem-solving skills, intercultural communication),
4. Transformative competencies (e.g., innovation skills, change skills, dialogue, conflict skills) (see figure 1).

The Stifterverband and McKinsey (2021) emphasize that transformative competencies are playing an increasingly important role as they are fundamental to courageously shaping social change by creating awareness of societal challenges and supporting both the development of visionary solutions and uniting people. This is confirmed by their survey conducted among 500 German enterprises and public authorities, stating the importance of transformative competencies. In this context especially the skills of dialogue and conflict ability as well as the ability to make judgments are emphasized as particularly important. In addition to transformative skills, digital key competencies (e.g., digital literacy) and classical skills (e.g., ability to solve problems) are also highlighted and it is predicted that these will continue to gain in importance over the next five years. (Stifterverband & McKinsey, 2021)

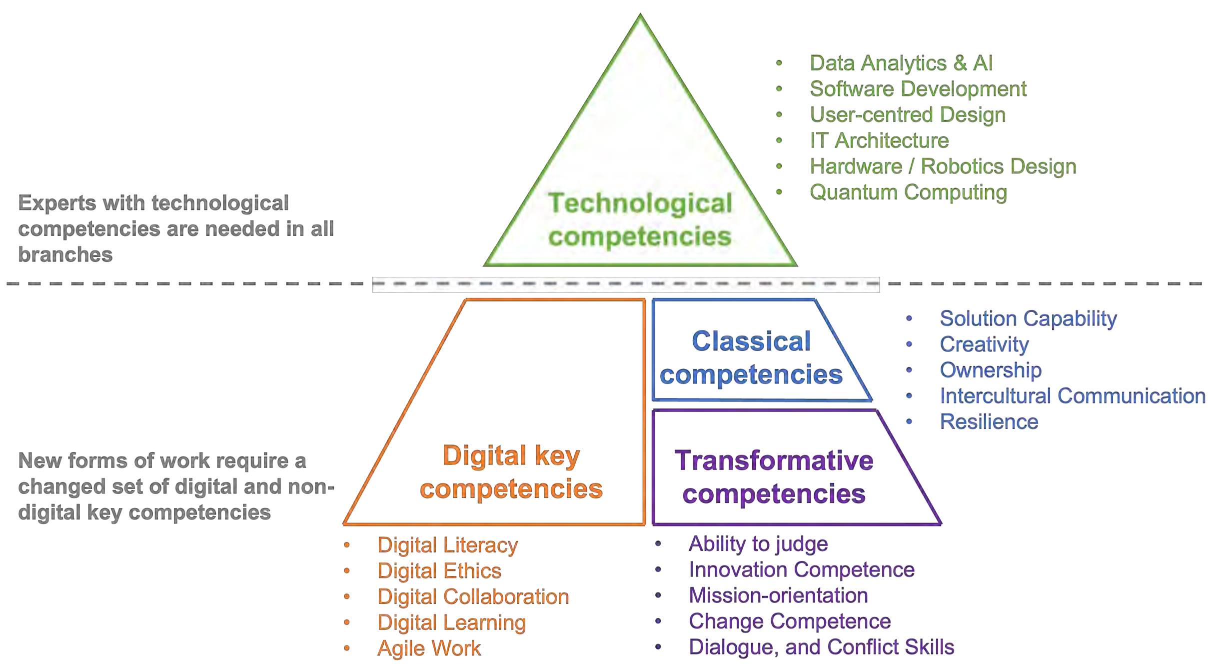

Figure 1. Future Skills (Own illustration following Stifterverband & McKinsey, 2021)

Because higher education has also become aware of the need to teach such skills, there are already various approaches. Alswad and Junai (2022), for example, see potential in integrating debate as an educational tool as it helps students to improve "[…] their critical thinking, increase the retention of the information gained, enhance communication and teamwork skills, promote their confidence and help them to better construct their ideas and thoughts in a logical and sound structure." (p. 1003). Summarizing Alswad and Junais (2022) experiences, the deliberate use of debate as a method can address both classical and transformative competencies. Soleimani et al. (2022) conducted a study exploring the sustainability of knowledge acquisition in the context of the SDGs. Their results show that personal reflection ensure a holistic acquisition of knowledge and conclude that reflection processes should be an integral part of teaching in higher education (Soleimani et al., 2022), which would also support the development of transformative competencies. Foley, Foley and Kays (2022) discuss the necessity of actively dealing with a culture of failure in engineering as it represents a "[…] necessary part of transformative learning in line with the intentions of CDIO." (Foley, Foley & Kays, 2022, p. 1009). In summary, there are different initiatives to rethink the engineering curriculum to be able to teach the future skills. Since previous approaches focus individual areas of competence to be able to teach them in the appropriate depth, the course presented attempts in a first step to tackle all four areas of competence and to make them a topic of discussion. However, since a more in-depth teaching of future skills is also to be achieved, a focus is laid on the competencies emphasized by the Stifterverband and McKinsey study (2021): the classical, the transformative and the digital key competencies. At this point, it is reflected that a more profound training of the respective competencies is more difficult if three competencies are to be addressed at the same time. The course therefore serves as a first step to deal with the new competencies and therefore needs to be integrated into a course of studies that ensures a more profound examination of the single competencies.

In the following, a block seminar is presented lasting a total of five days. The course is divided into two phases. The kick-off in the form of face-to-face teaching during the semester is combined with digital teaching outside the lecture period. Holding the block course outside the lecture period allows international students to participate from their home country. This enables the intercultural student teams to collect user perspectives and experiences directly at the respective location and thus to incorporate an intercultural perspective into the digital group work. This ensures an ongoing intercultural reflection of the group's innovation ideas. The innovative moment lies in the digital application of the design thinking approach and the inclusion of intercultural as well as trans- and interdisciplinary perspectives in innovation development.

COURSE CONCEPT

The course "Applying Design Thinking - Sustainability Perspectives, Innovation and Interculturality" aims to prepare students for their future work in an international environment. The 5-day course concept (Figure 2) consists of two elements. Day one in presence at the Jülich campus and days 2-5 as a digital block format outside the lecture period. The kick-off day at campus aims that students get to know each other personally during the semester and gain a scientific knowledge base on the topics of interculturality, sustainability and innovation. The course starts with the cultural dimensions according to Hofstede (2001), House et al. (2004) as well as Trompenhaars and Hampden-Turner (2012). The three concepts of cultural dimensions are discussed and reflected upon from the perspective of the different cultural backgrounds of the students. Based on the cultural dimensions and the resulting diverse perspectives, students are introduced to the scientific discourse on sustainability concepts (e.g., Morandín-Ahuerma et al., 2019; Pelenc, 2015; Dedeurwardere, 2013; Corsten & Roth, 2012). With the help of the sustainable development goals (SDGs) (United Nations, n.d.) the connection between diversity concepts (Gardenswartz & Rowe, 2003; Pelled, 1996; Loden & Rosener, 1991) and sustainability is clarified. To raise awareness through reflection on a personal level, the social responsibility of engineers and the individual role in societal transformation as well as the impact of diversity sensitive innovations (Gillwald, 2000; Mulgan, 2006) are discussed afterwards.

Building on the kick-off day (day 1), the digital design thinking challenge (days 2-5) takes place outside of lecture time. Days 2-5 focus on the teaching and practical application of the design thinking approach. Based on the scientific state of the art as well as the discourses about social innovations and the own role as an engineer in the development process, day two starts with an introduction to human-centered design and in this context design thinking. The experience of many years of teaching and applying design thinking has shown that especially engineering students are looking for a structure that provides orientation in a process. The open questions and the challenge of first understanding the problem from the perspective of the potential user and not arriving too quickly at a solution of one's own, turned out to be the main challenges for engineers in the design thinking process. The reason for this can be seen in the engineering culture which is influenced by the clearly structured processes, norms, and standards of the engineering working environment. While design thinking courses usually get to the part of the practical application quite quickly, design thinking formats with an engineering focus require an introduction to the design thinking process and a transparent explanation of the iterative process steps. This approach allows students to find their way through the process and gives them orientation and confidence. (see also Leicht-Scholten & Steuer-Dankert, 2020; Steuer-Dankert et al., 2019)

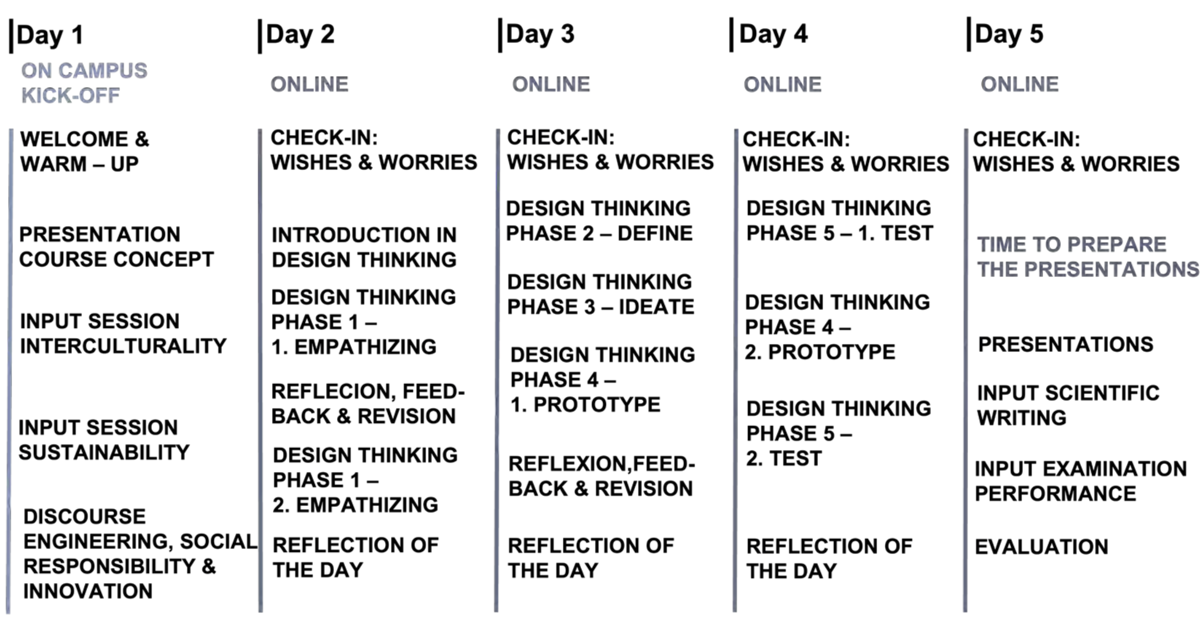

Figure 2. Course Concept (Own illustration)

To make the process more transparent and to convey the design thinking spirit to students, the 5-step design thinking process (Plattner et al, 2011) is applied (Fig. 3). A special focus is laid on the empathizing phase, giving students time to investigate user needs and perspectives in the respective country. Despite the defining and ideating phase (phase 2 + 3), students have two cycles to reflect their ideas with the potential target group and to improve their identified problem (phase 1) and solution (phase 4 + 5).

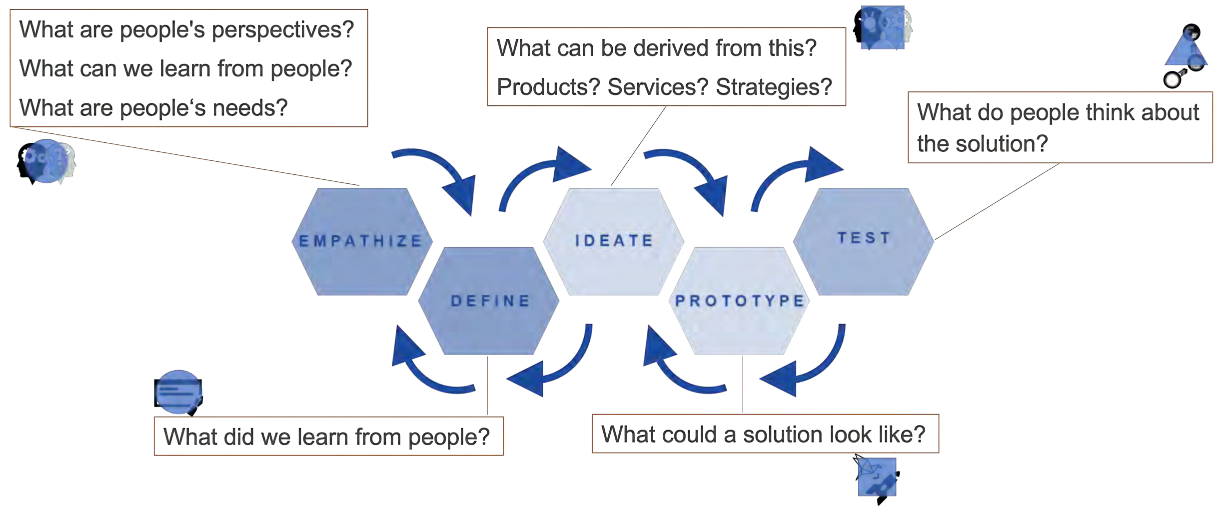

Figure 3. Key questions in the 5-step process (Own illustration)

The individual phases are discussed in more detail below:

Empathize & Define - Days 2 + 3

Students work in small groups whose group members belong to different nationalities. This entails different perspectives on innovation and collaboration in digital networked teams, as well as active contacts in different nations. To deal with the potential user needs, students contact people on site. Using quantitative and qualitative survey methods, they conduct surveys to identify the needs and perspectives of potential target groups in the sustainability context. In the next step, they bring together their findings and the different perspectives on the sustainability context in the digital learning space. The focus during the definition phase is to analyze the user perspectives and to identify the underlying problem or challenge. Especially engineering students need to be guided to focus purely on problem identification during the first two phases.

Ideate & Prototype & Test - Days 4 + 5.

In the further course of the process, the students develop innovation ideas based on their findings from the surveys and the derived user problems. Students then convert the ideas into digital prototypes (e.g., digital services, product ideas, concepts) which are then tested again on the target group. The digital implementation enables testing at the respective location and thus the continuous integration of intercultural perspectives on innovations. They are supported in this process by digitalized creative techniques (e.g., Disney Method, Six Thinking Hats, Crazy 8) and rapid prototyping methods. The development of the prototype and testing takes place in two runs to obtain user feedback and then incorporate it.

Reflection - Day 5

The examination performance consists of a final presentation as well as a reflection report. On the one hand, this trains the ability to create appropriate materials in a team environment, and on the other hand, it deepens the methods learned and trains presentation skills. In preparation, the students also learn how to write scientific texts. The final presentation (pitch) is held digitally on the last day of the course. The report focuses on the reflection of the individual steps and the respective insights that the group was able to gather in the steps. Based on this, it is deduced how the product idea was developed and which insights underlie the idea.

Another element of the last day is the teaching evaluation consisting of two elements. Element one is a quantitative evaluation questionnaire standardized by the university. The collected, mostly organizational, categories of the evaluation will be supplemented by element two, a focus group interview (qualitative approach), which should give an insight into the learning process of the students. A special focus in these interviews will be placed on the reflection of the acquired competences and their applicability in the future field of activity. Furthermore, the interviews will serve the continuous reflection of the teaching elements and the improvement of the course concept.

Course-Companying Elements

Especially with digital formats, there is a need for a joint reflection on concerns and factors that can impede digital collaboration. For this reason, days 2-5 are framed by reflection exercises that ensure transparent communication and the methodical monitoring of challenges. Every day begins with collecting and discussing students' concerns and wishes. Experience has shown that initially the main concern is not being able to be creative enough and that it is perceived as a challenge to approach potential users and ask the right questions (Steuer-Dankert et al., 2019). Teaching basics of social science research methods and implementing creativity exercises enables access to methods that help to cope with these challenges. On a social level, making these challenges transparent helps to recognize that this is not a subjective individual phenomenon, and emphasizes that different competencies within the team can also complement each other. To maintain the process character and allow an open and trustful reflection in the course, a code of conduct is used as an agreement within the course. The code of conduct includes aspects such as unprejudiced cooperation, respectful communication, and the courage to be creative, and is intended to contribute to an open and respectful course culture (Leicht-Scholten & Steuer-Dankert, 2020). Complementary to the reflection of wishes and worries in the morning, there is a daily reflection in the evening. As part of this daily reflection, the wishes and concerns mentioned are again addressed and reflected together with the students. In a group session, students reflect to what extent the challenges could be successfully mastered or which follow-up questions have developed over the day.

The creation of a safe working environment, where students can be creative and are open for a culture of failure (see Foley, Foley & Kays, 2022) is a key aspect of successful design thinking. Consequently, especially a digital design thinking course requires a constant moderation of the process. The challenge of a digital design thinking process consists in the precise alternation between open discussions in the course and the discussion of questions in the teams. Both formats require support and continuous responsiveness from the course leader. The teaching principle focuses on a moderation through the right questions and less the direct communication of the solution. In addition, interactive elements such as voting (e.g., via Mentimeter), and brainstorming sessions (e.g., via Miro) provide digital supportive moderation. Transnational teamwork is complemented by in-course reflection rounds where teams share their findings and experiences. The moderation of virtual discussion rounds within the course as well as teamwork phases enable peer feedback, which is complemented by group coaching by the course instructor.

In terms of credit points, the course is assessed at 6 ECTS to the scope of student work. Regarding the integrated study programs, higher semesters from the bachelor's programs Electrical Engineering, Mechanical Engineering, and Physical Engineering located at the

Faculty of Energy Technology are addressed in a first round. In a second round it is planned that the departments Biotechnology, Techno Mathematics and Medical Technology will implement the course in their study programs, too. The course will be part of the elective catalogue and is offered in both winter and summer semester. Regarding the organization of the two course elements, the aim is to have the kick-off course and the digital course take place fairly close to each other. However, the exam phases and the time until the international students have travelled to their home countries must be considered. Regarding these framework conditions, there is a time gap of one month between the kick-off course in presence (day 1) and the online course (days 2-5). As the time interval might have an influence on the students' willingness to perform and their ability to connect with the course contents discussed at day 1, a joint reflection with the students at the end of the course is planned, to discuss the impact of the time gap on the students’ learning outcome.

REFLECTION AND CONCLUSION

The purpose of engineering education is to enable students to “[…] get technical expertise, social awareness and the bias towards innovation. This combined set of knowledge, skills and attitudes is essential to strengthening productivity, entrepreneurship and excellence in an environment that is increasingly based on technologically complex and sustainable products, processes and systems. It is imperative that we improve the quality and nature of […] engineering education.” (Crawley et al. 2014, p.4). The CDIO standard 3.0 as a set of principles provides an overview of elements that enable future-oriented engineering studies.

In this paper, a digital design thinking teaching concept was presented which intends to convey future skills to future engineers. The course allows students to learn important future skills, with a focus on the classic, transformative, and digital skills - the areas of competence that, according to the study by the Stifterverband and McKinsey (2021), will gain in importance in the future (see figure 1). The concept was based on the CDIO standards 3.0 and addresses Standard 5, 6, 7 and 8 in particular.

Participants learn the practical application of the design thinking approach in interdisciplinary and international teams. Consequently, students gain experiences in the design of products, services, or systems by developing an idea basing on the user perspective. In this way, they gain transdisciplinary experience as they must combine scientific content with the experiences of people from the non-scientific community (Standard 5 - Design-Implement Experiences). As part of the course, students are involved in different working contexts. On the kick-off day students learn on campus in activating group work, then work in digital teams during the challenge and get in personal contact with potential users as part of the first design thinking phase (Standard 6 - Engineering Learning Workspaces). Students learn to work in an interdisciplinary and transdisciplinary manner and to link their findings with the specialist focal points. The active engagement with potential users of the sustainability challenge to be developed allows a new perspective on different cultures and the diversity of target groups. Thus, a contribution can be made to ensure that engineers reflect more strongly on social diversity and the effects of engineering developments by getting in contact with end users and key stakeholders (Standard 7 - Integrated Learning Experiences). Furthermore, students acquire competencies for their future professional activities, such as coordinating in intercultural as well as interdisciplinary teams, organizing collaboration in a digital setting and taking other perspectives into account. In addition, through the structure of the design thinking process, students learn to make decisions in a team setting within a short time frame and to transform them into a solution approach. The course format enables, direct feedback and complements the learning process with daily reflections and group discussions (Standard 8 - Active Learning). From a content perspective, students learn the basic principles as well as selected concepts of sustainability management (e.g., UN Sustainable Development Goals - SDGs), innovation management and diversity management. From a scientific perspective, students learn how to prepare presentations and reports according to scientific standards. In addition, students learn how to research scientific sources and how to apply them in the context of the reflection report.

In addition to the numerous potentials, there are also challenges. Working together in diverse teams not only offers potential but also challenges in group work (see Bartz et al., 1990; Nooteboom et al., 2007; Lorenzo et al., 2017). Therefore, close supervision of the groups and extensive sensitization for diversity and the resulting diverse perspectives are mandatory. There is also a challenge in the different time zones of the participants. This challenge should be made transparent to the students at an early stage and solutions for cross-time zone cooperation should be worked out together with the students. Another limitation is the number of course participants. The course is currently being conceptualized for 15-20 people, as close, digital support is difficult to implement for one teaching person.

If engineering education wants to contribute to overcoming global problems, then it must rethink its engineering curricula and create space for interdisciplinary, transdisciplinary and intercultural teaching formats. The course concept presented is intended to serve as an inspiration for how engineers of the future can be trained in order to be able to master the challenges of the future.

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SCALING UP PROJECT-BASED LEARNING IN ENGINEERING BEYOND 100 BSC STUDENTS: A PRACTICAL APPROACH

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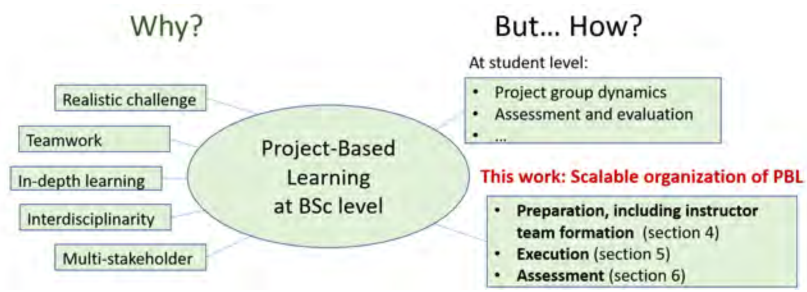
ABSTRACT

Project based learning (PBL) is commonly applied in engineering education, and evaluated positively in terms of learning outcomes and student engagement. However, ensuring depth of the taught material and limiting the workload per teacher is not obvious when implementing PBL, especially for large student populations. Here we share a practical framework to prepare and execute project based learning for groups of approximately 150 BSc students in Mechanical Engineering. We show how a team of Instructors and Teaching Assistants (TAs) allows reducing the workload of individuals in the preparation, execution, and grading phases of the project. In the preparation phase, pairs of TAs draft sections of the project manual that are tested and improved by different pairs of TAs. During project execution, the role of TAs is twofold: (1) They co-supervise two project groups together with one staff member, answering basic and administrative questions. (2) They act as experts for the project groups on the topics that they helped develop, which are sometimes outside of the direct scientific scope of the instructors. Therefore, the TAs act as *more knowledgeable others* in Vygotski's theory of constructive learning and therefore provide effective scaffolding, preventing students from getting stuck at places of difficult learning. The instructors (10 staff members, mainly of our research group) take responsibility for the execution and assessment phases to ensure quality, but at a strongly reduced workload because of TA involvement. The implementation schedule for the preparation, execution, and assessment phases of the project are included in the supplementary materials, as well as an example project description on Covid-safe train cabins.

KEYWORDS

Project-based Learning (PBL), Teaching coordination, Scaling, Durability, Agility, Quality , Standards 6,7.

GRAPHICAL ABSTRACT



INTRODUCTION

Teaching engineering is challenging, as engineering entails using *scientific principles* to *design and build* e.g. machines that *optimally make use of the resources* of nature (freely after Merriam-Webster and Britannica). Project teams in industry connect these elements, usually by bringing people with diverse backgrounds together to achieve effective solutions. Therefore, project-based learning (PBL) provides an outstanding opportunity to train engineering students in addressing complex and interdisciplinary challenges in technology and society.

The benefits of PBL include deeper understanding of the course material, knowledge retainment, communication and teamwork skills, and a social foundation for students (e.g. (Oakley et al., 2004)) and references therein). Challenges include group thinking in self-selected groups (Feichtner & Davis, 1984), insufficient weight of the project in the total grading, and lack of peer review. Research on PBL now provides solutions to most of these content- and learning related limitations. Hence, PBL is generally considered as an effective teaching method as long as pitfalls are prevented, and one that very well complements classroom-based teaching.

However, two interconnected challenges still exist in applying PBL:

(1) Scaling of project-based learning to groups larger than 100 students, as commonly required for education at BSc level.
(2) Design and execution of in-depth projects that connect a broad context, scientific analysis, and science-driven design and optimization of a realistic case.

Therefore, implementing PBL of complex projects for a large student population is far from obvious.

To address these challenges, our team developed a framework to design, execute, and assess in-depth projects for large groups (150 BSc students). A key goal is to keep the workload manageable for the instructors (staff members of our research group) while ensuring an in-depth learning experience for the students. To a large extent, these goals are met by involving a group of teaching assistants (TAs) in all phases of the project, including:

- Preparation and testing of new project manuals;
- Group supervision and question hours;
- Written assessment.

Here we qualitatively describe key learnings from combining and refining existing methods over the past years. In our view, these have made a profound impact on the quality of the project as well as the workload and enthusiasm of the staff and the TAs. The goal of this article is to share our learnings, to inspire fellow teachers who face the challenge of implementing PBL of complex topics to large groups. Thereby, we hope to contribute to the education of the next generation of engineers, in particular their realistic problem solving ability. In the following, we concisely review the state of the art on scaling of PBL. Subsequently, in section 3, the learning goals of the project are discussed. Section 4, 5, and 6, describe the preparation, execution, and assessment, respectively. Our experiences are concluded in section 7, including an outline for future improvements.

STATE OF THE ART

Scaling project-based learning

Implementing PBL has a high threshold for faculty members, as simultaneous changes are required in the curriculum, instruction, and assessment (Barron et al., 1998). These challenges become even more significant for large student populations, where feedback is required for many project groups (Domínguez & Jaime, 2010). Google Scholar searches on "scaling project-based learning" and "project-based learning for large groups" revealed several strategies for scaling PBL. For laboratory projects, Sanders et al. (Sanders et al., 2016) described how a bring-your-own device (BYOD) concept alleviated the need for large amounts of equipment. Laboratory projects for 60 students were held manageable by dividing daily supervision among TAs, unifying the tasks of each group, and a clever exchange of technical information between groups that motivated all groups to perform well. For large student populations, peer-assisted feedback within groups (Robinson, 2013) and between groups (Bhavya et al., 2021; Sanders et al., 2016) is widely applied. Meta-review of the student's peer reviews by teaching assistants adds credibility and consistency to peer review among students (Bhavya et al., 2021). Botha (Botha, 2010) describes a project for 1500 BSc students, where non-written assessment of entrepreneurial activities was a key element in keeping the workload manageable. Alternatively, a population of 2000 MSc students was divided into subgroups of up to 30 students, that each execute their own project under supervision of one staff member (Wallin et al., 2017). Dominguez and Jaime (Domínguez & Jaime, 2010) applied PBL to a subset of students of a course in database design learning, reporting that PBL results in higher grades but at a larger time investment of students and teachers. More examples of PBL were very comprehensively reviewed and tabulated by Chen and Yang (Chen & Yang, 2019), but the provided examples of PBL for more than 100 students are limited to subgroups smaller than 50 students that were spread over multiple years or multiple classrooms.

In the above references, no example was found for scaling of projects in BSc education with a high level of complexity. However, solving real-world engineering problems requires analysis of many elements that may grow in complexity or uncertainty when more information is obtained. To solve such "wicked" problems effectively, a rich knowledge background and experience with related problems and their solutions is highly beneficial. Connolly and Begg (Connolly & Begg, 2006) describe how PBL was implemented in small groups, to address wicked problems in database analysis and design. Similarly, effective engineers must be able to systematically solve complex problems. Below, we describe how PBL was implemented to teach high-level problem solving skills in engineering to a large group of students.

CONTEXT AND CONTENT OF THE COURSE

At the University of Twente (UT), PBL has been part of the bachelor in mechanical engineering (ME) since 1994 (Peters & Powell, 1994). Here we focus on the project in Thermal and Fluid engineering, part of the second year of the BSc in ME. The students have participated in 6 projects before starting our project in Module 7 of the BSc. About 150 students follow the project. The weight is 7 European Credits (EC), equivalent with a total study load of 196 hours. The project is accompanied by courses on Fluid Dynamics and Heat Transfer of 3.5EC each, as shown in Figure 1. Combined, the project and the courses form a module that spans 9 week, including two weeks for examinations. Part 1 of the project (2 weeks time) only includes phase 1: the literature review. This focused start was chosen as it does not require prior knowledge of fluid mechanics and heat transfer, and to allow them to set up their team. Part 2 of the project contains all other activities except assessment and is planned by the students. Here, their knowledge from the literature review and the initial course materials enables them to start with the fluid and thermal analysis part of the project (phase 2). Based on the literature and this technical analysis, the students design an optimal solution (phase 3). In parallel to phases 2 and 3, the students conduct an ethical analysis and an experiment. The project is concluded with a project report describing all results, which is graded per group. An oral exam leads to an individual grade, which is weighted equally to the report grade. All project information is shared with the students via a Canvas environment.

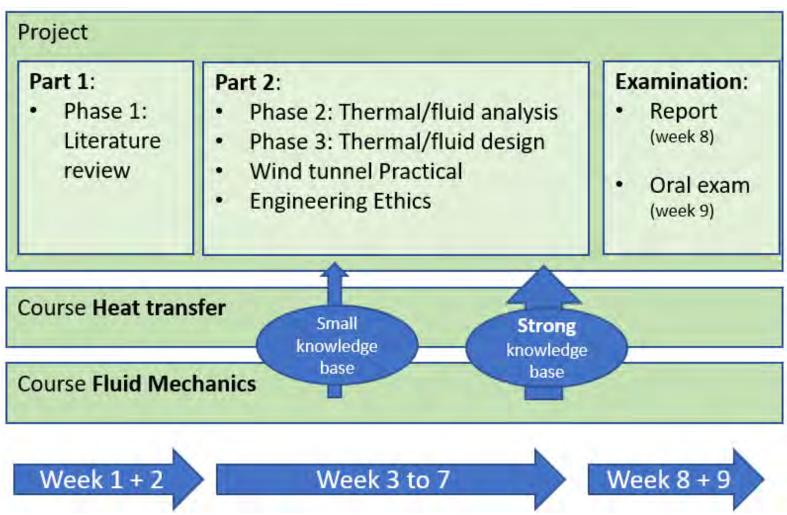


Figure 1: Project overview

Learning goals

The following learning goals are pursued during the project.

1. ***Phase 1: Literature review**. Given lectures on finding, reading, and writing scientific articles, students are able to do independent literature research as demonstrated by a report chapter in which two important designs are investigated and compared based on at least 10 academic references per design.*
2. ***Phase 2: Analysis of heat transfer and fluid flow**. Given lectures on heat and mass transfer, the students are able to model the system both numerically (with an explicit first-order solver they develop) and theoretically (with a simplified, lower-dimension model), discuss the two main limitations and two boundary conditions of each approach, and compare the results.*

3. ***Phase 3: System design**. Based on the literature review, a lecture by experts from industry, and a numerical solver (OpenFoam), the students are able to design and optimize a realistic system configuration. The relevant boundary conditions must be incorporated, and the main limitations of their modeling approach must be discussed.*
4. ***Engineering Ethics**: Given an ethical case and two ethics lectures, the students are able to evaluate the impact of their work from an ethical perspective based on applying the 7-step framework* (Van De Poel & Royakkers, 2007) *as provided in the lectures.*
5. ***Experimental**: Given a written tutorial, basic knowledge of MATLAB, and an oral instruction, subgroups of 2 to 3 students are able to derive a theoretical model for a simplified but relevant version of the system, build the corresponding setup at home, perform measurements, and compare the results between theory and experiment.*
6. ***Dissemination**: Given lectures on report writing and project planning, the students are able to effectively communicate their results by delivering well-organized, complete, and well-written reports within the deadline and substantiate their report in an oral exam.*

The learning goals are translated into the project manual, of which an example is provided in supplementary information (SI) file 1. The project manual contains the "case description" including a general introduction that states the societal relevance as well as the technical challenge. The manual includes starting references for the literature review, guiding questions for the analysis and design parts, the ethics assignment, and practical details such as the submission deadlines for sections or reports and the examination dates. Additional descriptions are provided for guiding the experiments (SI file 2) and OpenFoam (SI file 3). The performance levels are described by a Rubriks (SI file 4).

PREPARATION OF THE PROJECT

Formation of the instructor team

Ideally, the instructor team for a group of 160 students consists of 10 academic staff members including one project coordinator and 10 TAs. "Tutor teams" that consists of one instructor and one TA then supervise two project groups of eight students each.

The TAs are typically 3rd or 4th-year students who participated in the project as 2nd-year students. Therefore, they are familiar with the level of the students and can judge which topics would be exciting for the future students to learn about. To attract an academically strong and enthusiastic team of TAs, we select a strong project group and invite this group to become our TAs for the next year. We select this group by discussing among the instructors which group stood out in terms of academic performance during the project, ability to collaborate, and enthusiasm. Approximately 50% of the students that we approach become TA. This is a profound improvement as compared to posting TA vacancies on general platforms, which previously resulted in fewer candidates with mixed credentials. The group of TAs is completed by experienced TAs that stay on for another year. As described below, the TAs are trained in-depth on different parts of the content of the project in the preparation phase, enabling them to guide the project groups building on this knowledge.

The instructors are staff members of our research group. Since the TAs cover the technical details of the project, the instructor pool can be flexibly expanded by experienced staff in thermal or fluid engineering, or even adjacent STEM disciplines such as solid mechanics or materials science. As the workload is manageable and leads to two-way learning on the project topic, our staff happily participated. Over the past year, the instructor pool was even frequently expanded by staff from other groups who volunteered to join! Guidance of more than two project groups per staff members is possible, but during the examination week this approach requires reading more than four reports within a few days which is challenging. Therefore, we aim for at most two project groups per staff member.

Take-away: A pool of instructors and TAs is created more than 6 months in advance. The TAs are trained to become enthusiastic experts who keep the workload manageable during execution of the project.

Preparation and testing of the project manual

The project is mainly prepared by the project coordinator and the TAs. After choosing a topic together with the instructors, key sub-topics are selected and placed in context by the coordinator. Subgroups of two or three TAs develop questions on these topics (Figure 2) and design the experiments, that will eventually constitute the core of the project manual. The project coordinator guides this process in biweekly meetings with the TAs. Simultaneously, the coordinator aligns the project with the lecturers of the accompanying courses (*Fluid Mechanics I* and *Heat Transf*er).

As shown in Figure 2, each topic is drafted by two TAs and tested by two different TAs. The four TAs then together improve on the question, and provide an answering model that benefits the instructors during the project. In this process, the TAs identify threshold concepts and pitfalls that the students will experience, as well as the order of magnitude of the outcomes. The testing by the TAs reduces errors in the project manual to a level that minimal changes are required during the project, limiting questions and complaints from both students and instructors. In addition, these four TAs become expert on the topic that they developed together. They are positively challenged and become knowledgeable on creating complex project, making them better engineers too. They develop into advanced learners to a level within the zone of proximal developments of the students. Therefore, the TAs are very effective in answering specialized questions on “their” topic and the lead in answering these during execution.

One month before starting the project, the draft project manual is checked by the coordinator for consistency. The instructors also receive a draft copy including answers developed by the TAs, providing them the possibility to comment and improve. The project manual is finalized in the week before the start of the project, and distributed to the students on the first day of the execution phase.

Take-away: New project manuals are created and tested primarily by the TAs, lowering workload for the staff while training the TAs as experts to answer questions during project execution.

Formation of the project groups: Hybrid between self-formed and instructor-formed groups

The project groups of 8 students are formed on the first day of the project, by combining self-chosen sub-groups of up to 4 students.

In this way, we balance two needs. On the one hand, combining students that may not know each other aids their exposure beyond their friends and reduces the risk of group thinking. If applicable, we divide the (few) female students who are not part of a subgroup into either zero or at least two women per group (Feichtner and Davis 1985). Simultaneously, the subgroups protects students by minimizing their risk of isolation, as they can team up with friends. After 6 modules with teacher-established project groups, students crave for a project with a self-formed group. After initial experiences with fully self-formed groups, this hybrid approach functions to the satisfaction of instructors and students.

The resulting project group size of 8 students exceed the typically recommended maximal group size of 5 to 7 students (Oakley et al, 2004, Feichtner and Davis 1985), but fit our project well as the student are sufficiently matured in PBL. As our project is large in scope and duration, groups typically divide themselves into smaller sub-groups that work on specific learning goals. This is allowed by the instructors, as learning goals (phases) 1, 2, and 3 can be carried out separated in time, and are sufficiently broad in scope to allow the subgroups to work on different aspects of each learning goal. For learning goals 4 and 5 (ethics and practicals), all students have to personally participate in smaller assignments to ensure obtaining the desired knowledge level.

Take-away: Large project groups that are partly self-selected enable effective learning for students that have experience with PBL.

Phase	Topic	Preparation	Testing	Final check	Execution		
Phase 1	Lit. Review	Coordinator					
Phase 2	Topic 1	TA1 + TA2	TA3 + TA4				
	Topic 2	TA1 + TA2	TA3 + TA4	Coordinator + Instructors			
Phase 3	Topic 3	TA3 + TA4	TA1 + TA2			Planning and execution: decided by project groups	
	Topic 4	TA3 + TA4	TA1 + TA2				
Ethics		TA5 + Ethics-Instr.					
Practical	Exp.1	TA1 + TA3	TA2 + TA4				
TIME:		Sept+Oct	Nov+Dec	Jan	Feb	Mar	Apr

Figure 2: Example of phasing and work distribution during the preparations of the project. The red bar indicates the oral exams.

EXECUTION OF THE PROJECT

Supervision of the project groups

Each project group is guided by a tutor team that consists of one instructor and one TA. Typically, the instructor and the TA meet with each group once per week. The goal of the meetings is to discuss progress, to ensure that all major project goals were addressed by each group, and for informal formative assessment. The role of the instructors in project group supervision is twofold:

1. Provide the students broad context in fluid mechanics and heat transfer, by explaining key principles or underlying mechanisms.
2. Help resolving insufficient performance or conflicts.

The role of the TA during the project is complimentary:

1. Help organizing the meetings with the instructors.
2. Provide answers to questions on specific content or results, based on recent experience with the project in the same role as the students in the project group. Their role as more knowledgeable other in the zone of proximal development (McLeod, 2012) bridges the communication gap arising from the difference in experience between the instructor and the students.
3. Guide students to TA-specialists on specific topics if knowledge beyond that of the instructor and the assigned TA is required.
4. Occasionally meet with the project groups alone, in case of absence of the instructor.

Take-away: The TAs form a bridge between the project groups and the instructors, enhancing the learning of the students and preventing that trivial questions take the instructor's time. At points of difficult learning the scaffolding by the TAs is especially effective.

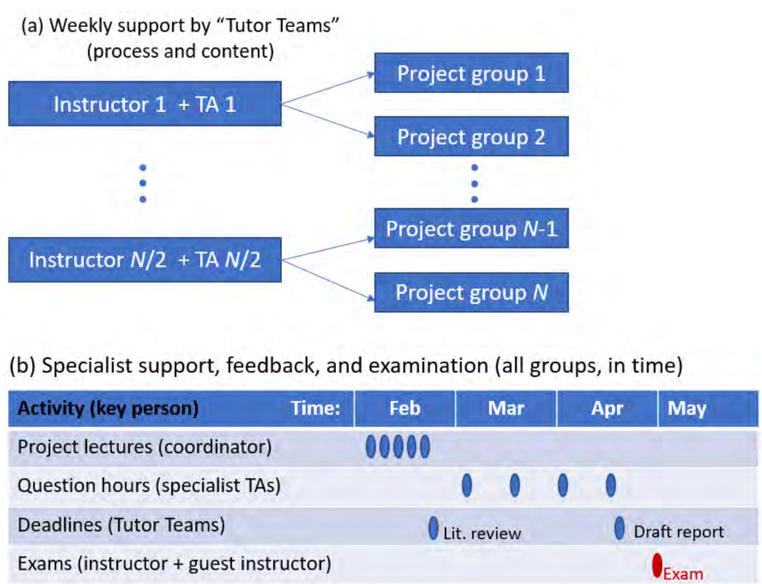


Figure 3: Support of the project groups. (a) Each project group receives weekly support on content and process from one tutor team. Each tutor team guides two project groups. (b) TA "specialist support" for lectures and question hours is available throughout the project. The deadlines for the literature review and draft report are indicated. Here, the tutor teams provide formative feedback. Examination (oral and grading of the report) is executed by two instructor (including the one from the tutor team).

Scaffolding: Project lectures, question hours, and online help

Project lectures are scheduled in the first three weeks of the project, to familiarize the students with the topic and content of the project. Six lectures are scheduled as follows:

1. Introduction lecture. Here, the topic is introduced, the workflow of the project is shared with the students, and planning tools (Gantt chart) are refreshed;
2. Lecture on reviewing academic literature, by an information specialist from the UT;
3. Ethics I, providing an introduction to ethics. The ethics lectures are delivered by an ethics teacher who is familiar with engineering students;

4. Guest lecture by company/organization that relates to the project topic;
5. Ethics II, providing a toolbox that students have to apply to an engineering ethics case.

Online help: A question board is provided via Discord. Here, students ask questions at any time and TAs help them typically within 2 days. The goal is to prevent students to get stuck for too long on less-important issues, such as scientific software that might not work or complex mathematics that has no direct connection to the engineering challenge. Building on their knowledge from the project preparation, the TAs (together) provide the role of topic-expert during the question hours and the discord server. This approach prevents excessive preparation by instructors for which the project is outside their core research area.

Plenary *Question hours* are organized with two instructors and two TAs. These question hours are held weekly, starting from week 4. The meetings are in-person, enabling the instructors and TAs to identify questions that occur in multiple project groups. Such major bottlenecks could be addressed on-the-spot or by providing additional documents via the project website on Canvas.

During the project, scaffolding leads to growth and maturation of the students that we see most clearly reflected in the level of the students' questions during the question hours. For example, in the first weeks, students would get really dissatisfied with a poorly posed question or high-level guidance (such as: you may try a, b, or c, instead of pointing to the "correct" answer). Towards the end, the students would say: "I read the question, I tried a, b, and c, I made assumptions X and Y, and then I obtain two possible results that are a bit different. Can you help me to understand how to address this difference and how to choose?". We believe that this step in the development of students is critical in becoming effective engineers.

Take-away: The paradox between (1) PBL, (2) going in-depth with a large group of students, and (3) managing workload is solved by providing strong scaffolding (lectures, question hours, and online help) in a joint effort by instructors and TAs.

How to connect the project with courses that run simultaneously?

In initial versions of the project, it was shifted by 4 weeks with respect to the courses (starting earlier and running longer). This time-shift enabled the students to acquire working knowledge from the courses on fluid mechanics and heat transfer that they could apply to the project. After a UT-wide shift to self-contained 9-week modules that each includes courses and a project, the project and the courses run simultaneously. Therefore, students cannot build on working knowledge from the courses on fluid mechanics and heat transfer at the start of the project.

To maintain an interesting and on-topic project, the literature study (one of the learning goals) was condensed and implemented in Phase 1 (the first two weeks of the project). The literature review was supported by a lecture of an information specialist. This approach has several benefits:

- This knowledge provides the context for part 2 of the project. The students become involved in the topic and are able to analyze and design relevant solutions in the later phases of the project.
- The students focus on literature reviewing without having to integrate this new skill with other learning goals.

- The students train their reading skills of academic material (as opposed to teaching material), preparing them for their future BSc and MSc assignments.

ASSESSMENT OF THE PROJECT

Formative assessment

Two weeks before the report submission deadline, each project group was required to submit a draft report for formal formative assessment. The tutors and TAs both provided feedback on these reports with a focus on learning goals 2,3 and 6.

Summative assessment

The final grade of the students consists for 50% of a group-based grade for the report, and for 50% of an individual grade based on an oral exam. For the report, the Rubrics (SI file 4) shows the expected level per learning objective. However, the grading can deviate from the Rubriks. For example, mutually inconsistent subsections are reflected by lower grades, and truly in-depth or creative work is rewarded with more points. The instructor assigned to a project group and one additional instructor graded items 1, 2, 3, 5, and 6 of each report. At least one of these instructors was experienced, in having executed the project in previous years. Learning goal 4 (ethics) was graded by the Engineering Ethics teachers. In addition, sections of all the reports were graded by the TAs for learning goals 2, 3, 4, 5 and 6. These sections corresponded to the expert knowledge of the TAs. This approach of combined per-report grading and per-section grading was chosen to assess consistency between the assessment of different groups while keeping the workload manageable. The grades from the instructors and TAs were normalized on a scale from 1 to 10 (any grade above 5.5 represents a pass), and are compared in Figure 4. The general trend is that a correlation exists between grading by the instructors and the TAs. However, the instructors grade on average a 6.9 with a standard deviation of 0.8, whereas the TAs grade on average 6.5 with a standard deviations of 0.7, based on grading of 16 project groups. For the three largest outliers the instructors gave +0.8 points or more relative to TAs. These differences originated from three different tutor teams, and given for reports that show good internal coherence or creative ideas despite weaknesses in specific sections.

The individual grades were determined during the oral exams, by the tutor team as well as the additional instructor who graded the report. The first 45 minutes, each student was asked 2 to 3 questions about a part of the report. If the student knows the answer, we probed for more depth to find the limit of knowledge. If the students do not know the answer, the fellow students are allowed to step in and help or answer. In this fashion, the first 45 minutes usually gives a reasonable indication of the knowledge level of each student. In the second hour, additional questions were asked. Here, students whose performance was not clear from the first 45 minutes is assessed by asking additional questions.

The relatively heavy weighing (50%) of the individual grade was chosen to incentivize individual contributions to the project. For some groups, the individual grades were comparable to the group performance. For other groups, free riders or exceptionally talented students were identified during the orals, and adequately graded. The time slot (2x45 minutes) was chosen to provide a balance between assessing the students fairly and maintaining the positive atmosphere required for a fruitful discussion. Longer exams had been tried in previous years, but all staff agreed that it merely led to exhaustion of both students and staff during the exam.

Take-away: Hybrid oral and written assessment by tutor teams and one extra instructor per project group provides a balance between time consumption of the instructors and precision in the grading.

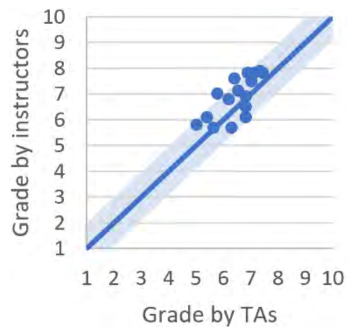


Figure 4: Comparison of grades for the reports provided by the instrutors and the TAs. Each data point indicates one project group. The line indicates equal grading, the shade indicates the ±1 point bandwidth

CONCLUSIONS AND OUTLOOK

We describe practical suggestions for impementing of PBL for large groups of BSc students, aimed at reducing the workload per instructor by attracting and educating a pool of TAs and by spreading the supervision and assessment load among instructors while improving the depth and quality of the learning.

A team of instructors and TAs is created over 6 months in advance. New project manuals are created and tested primarily by the TAs, lowering workload for the staff while training the TAs as experts to answer project-specific questions during project execution. During the project, the TAs also form a bridge between the level of the project groups and the level of the instructors, enhancing the learning of the students and preventing that trivial questions taking the instructor's time. The paradox between (1) PBL, (2) going in-depth with a large group of students, and (3) managing workload is solved by providing strong scaffolding (lectures, question hours, and online help) in a joint effort by instructors, TAs, and guest speakers. Hybrid oral and written assessment by tutor teams and one extra instructor per project group provides a balance between time consumption of the instructors and precision in the grading.

Reducing the per-person workload for an in-depth BSc project for a large group of students has broadened our knowledge on content, improved interaction between teachers and learners, and enhanced our motivation to be examples to our students. Future work may improve the scientific embedding of this approach, and more systematically evaluate the impact of changes made on the project outcomes.

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SUPPLEMENTARY INFORMATION

The supplementary Information is available online via de CDIO website.

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PNEUMATICS LABORATORY INTERACTIVE EDUCATIONAL EXPERIENCE DEVELOPMENT

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ABSTRACT

In the recent past, gamification has been promptly developing as well as actively applied in the educational sector. Nowadays, it figures prominently on account of making the learning process more engaging and motivating which leads to enhancement of the quality of gained knowledge. The preservation of the existing level of education or, moreover, its strengthening. Additionally, these tools enhance and support the contactless learning methods that emerged during the COVID-19 pandemic. The redeployment of laboratory works into the gamification experience format allows students to perform tasks without the necessity to attend the designated laboratory room as well as reduce its utilization. The main objectives of the gamification experience are the establishment and contribution of the virtual tool to the Educational Game Project that is being developed by the Virtual and Augmented Reality laboratory at Tallinn University of Technology. The laboratory of the "Hydraulics and Pneumatics" course is utilized in order to prepare educational videos. The primary software tool implemented in the project is the Unity game engine due to its broad functionality while collaborating with 2D and 3D environments. Once a student has completed the designated task, they gain access to the next laboratory work as well as can revise their previous assignments. Current work presents the process of digitalization of the lab with the analysis of students' feedback on comparison between in-class and remote learning in the same lab.

KEYWORDS

Gamification experience, Pneumatics, Remote laboratory, Interactions, Standards 6, 8, 9, 10, 11, 12

INTRODUCTION

In recent years, gamification has been rapidly developing and applied in the educational process. The term "gamification" is generally used to denote the application of game mechanisms in non-gaming environments to enhance the processes enacted and the experience of those involved. The term has become a catchword throughout the fields of education and training, thanks to its perceived potential to make learning more motivating and engaging (Caponetto, Earp & Ott, 2014), especially among younger generations. While commonly found in marketing strategies, it is now being implemented in many educational programs as well, helping educators find the balance between achieving their objectives and catering to evolving student needs (Mertala, 2019). As a result, the elements of novelty in performing learning tasks are among the most critical factors for this development (Shevtshenko, et al, 2017).

The role of gamification in engineering education has become increasingly central and prominent with growing adoption in different areas of education and particularly software and computer engineering (M. Milosz & E. Milosz, 2020). Gamification tools and methods have beneficial effects on how students learn and process information. Interactive games in education stimulate interest and increase critical thinking, boost problem-solving competencies (Anil Yasin & Abbas, 2021), and are proven to increment academic performance, collaboration, and teamwork skills (Díaz-Ramírez, 2020). The development of new teaching methods in engineering is strictly bound to the development of new technologies in the field of industry. The ongoing and forthcoming transformations in the manufacturing field and Industry 5.0 (I5.0) are forcing education to adapt to new requirements, competencies, and skill sets (Broo, Kaynak & Sait, 2022). Multidisciplinary project developments, human-centric production lines, data-driven intelligent systems, and highly sophisticated collaborative work processes, in which humans and machines mutually learn from each other, are pushing higher education to provide adequate minds and skillsets to future engineers and technicians. In this regard, gamification and advanced collaborative interfaces, such as the one provided by augmented and virtual reality (Lampropoulos, et al, 2022), can be beneficial and preparatory to those future challenges. The examples in the literature are, of course, diverse but show a lively scenario of varied applications with mobile-based augmented reality interactive tools (Criollo, et al, 2021), the implementation of leaderboards (Ortiz-Rojas, Chiluiza & Valcke, 2019), the application of immersive Virtual Reality (VR) in automotive design teaching (Cordero-Guridi, et al, 2022), or the development of a dedicated toolbox for the analysis, virtualization, interaction, and exploitation of virtual factories and production lines for education though web tools (Mahmood, et al, 2021).

The main objectives of the presented application are the creation and implementation of a virtual tool into the Educational Game Project to digitalize methods of learning Pneumatics and Hydraulics. The project is being developed by the Virtual and Augmented Reality laboratory at Tallinn University of Technology. The gamification experience is conducted in a desktop-based 2D environment and the design of the gamification experience is inclusive of the "Main Menu" and 9 laboratory works on Pneumatics and 4 laboratory works on Electro-Pneumatics with corresponding educational videos. The task of each laboratory work is to compose a schematic, namely, the selection of the necessary components and the construction of connections between them. For this reason, a fundamental aspect of this work is collecting a library of symbols that represent Pneumatics components. The algorithm for performing and ascertaining the schematic for the correctness of each laboratory work is included in this work.

MATERIALS AND METHODS

The main software used in the development is the Unity game engine. Unity is widely employed to create games and interactive 3D and 2D experiences, e.g., training simulation, medical and building construction (Li & Tang, 2019). This software includes a wide range of tools and packages allowing to accomplish the designated task entirely. Furthermore, the application includes numerous C# scripts that are written using Rider by JetBrains. The current study is inclusive of a 2D space from which a student accesses the virtual Pneumatics laboratory. The gamification experience provides an opportunity to conduct Pneumatics laboratory works remotely decreasing the necessity of contact learning and the use of physical Pneumatics components. Pneumatics laboratory tasks are transferred into the gamification experience and a student is presumed to construct a schematic in conjunction with a step diagram. To endow the virtual environment with an ergonomic interface, the gamification experience is inclusive of the “Main Menu” for laboratory work selection and advancement observation. Upon starting the gamification application, the user is suggested to select the required subject and subsequently the laboratory work number. This activates the algorithm that allows access to the laboratory works exclusively after the successful completion of the previous task as students are required to accomplish laboratory works consistently. The transition between the laboratory works is initiated automatically and immediately after the total amount of laboratory works is completed. The application allows for the construction of schematics with an unlimited number of attempts. Students can navigate back to the “Main Menu” to either withdraw the gamification experience or revise laboratory works. A representation of the gamification experience system and logic is shown in Figure 1.

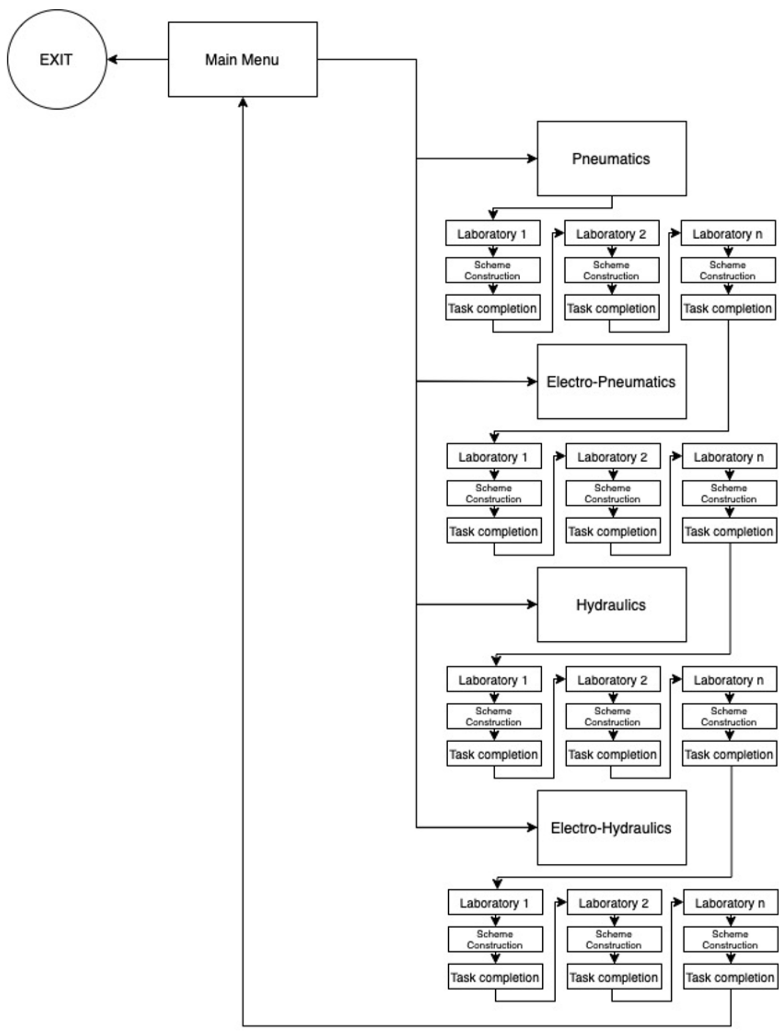

Figure 1. Gamification experience system diagram

The gamification experience is conducted directly on individual Scenes. These can be defined as assets containing all or parts of a game or application within the Unity environment interface (Unity, 2022). Each Scene contains GameObjects, which represent various formats and perform predefined functions, e.g., interact with other objects within the Scene. Such operations can be performed by dint of the Event System. The Event System is a way of sending events to objects in the application based on input, be it a keyboard, mouse, touch, or custom input. The Event System consists of a few components that work together to send events (Unity, 2022). In addition to that, GameObjects can represent colliders, which are used in this work to access the virtual laboratory from the Educational Game Project. Colliders allow for the creation of events that occur in the case of an interaction with the object to which it is assigned.

USER INTERFACE

Since the gamification experience on laboratory works is a part of the main Educational Game Project which includes an avatar as well as a 3D model of the university, the access to the laboratory works is accomplished through a user avatar interaction with a Personal Computer in the Virtual and Augmented Reality Laboratory Digital Twin of the IVAR lab at Tallinn University of Technology. This was developed prior to the current research, based on the digitalization and gamification of the student interaction with the university. To activate the interaction a Raycast method is used. Numerous games use the Raycast approach to execute interactions with virtual objects. In broad terms, "Raycasting" can be defined as a method of casting a ray from a specific point, e.g., a main camera, to detect intersections with scenes components called colliders which are attached to specific GameObjects in the scene. The ray turns red in case of encountering an interactable object informing the user he can interact with it. In the case of the PC, this indicates the possibility to access the Pneumatics laboratory work. The representation of Raycasting when detecting an interactable object is shown in Figure 2.

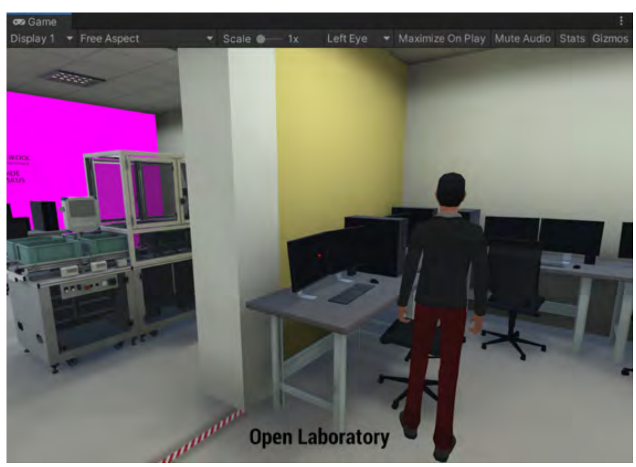

Figure 2: Raycasting once detecting an interactable GameObject

A student executing any laboratory work will be able to visualize the main application user interface (UI). Main UI includes the specific work task requirements, the inventory of the pneumatics symbols, an empty area dedicated to the construction of the schematics as well as buttons that are responsible for the removal of the created connections, reset of the work to the initial state, return to the "Main Menu" and check the composed schematics for correctness. An illustration of the first laboratory work's initial state description UI can be seen in Figure 3.

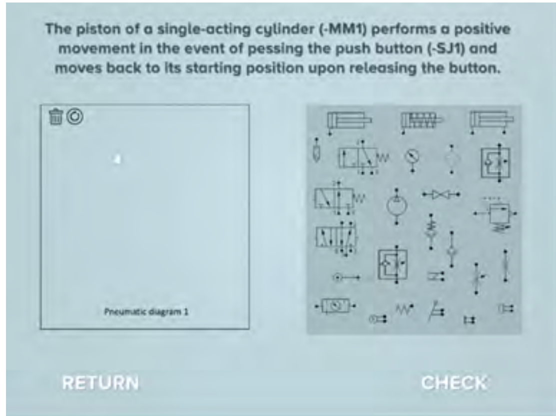

Figure 3. The initial state of the first laboratory work

The application suggests the user construct a schematic based on the selection of the appropriate components from the inventory of the symbols as well as draw the corresponding connections between them. Immediately upon the schematics being composed the student can assess the correctness of the answer by pressing the “check” button in the user interface. In the event of inaccuracy detection, a pop-up notification window appears on the screen. At this point, the student should continue with the construction and modification of the schematic. When the schematic is built correctly the pre-recorded educational video of the detailed illustration of the process of construction and execution of the circuit is visualized in the UI.

Inventory of symbols

The inventory includes all the components’ symbols that a student would have in a real Pneumatics and Hydraulics Laboratory at Tallinn University of Technology. The illustration of the symbols was obtained from the educational materials on the “Hydraulics and Pneumatics” course and later digitalized. To be able to interact with the symbols, these have to be imported into Unity. Here the textures are transformed into interactable GameObjects called sprites and included in Unity UI components. The term “Sprite” is generally understood as a 2D Graphic object used in two-dimensional application development. The inventory includes single and double-acting cylinders, directional control valves, various control methods, flow control valves, filters, a manometer, a silencer, a compressed air service unit, and a pressure source. Every component is defined as an “Entity” by means of a C# script attached to the corresponding GameObject and the fundamental aspect of the script is storing the list of nodes involved in the component. Depending on the polarity type, the nodes can be distinguished by In, Out, or In-Out which creates a possibility for further deviation between the nodes to compose connections. For instance, nodes of two different components cannot be connected since input nodes connect to output one exclusively.

User Interface functions

The subsequent step in schematic construction is to create connections between the components. This function is implemented by means of a purchased Unity plugin. Connections are created in the following way. A line is drawn from the first node by clicking on it with the mouse pointer. After this, the node with which the user desires to create a connection is selected allowing for the creation of the connection line, existing as a separate GameObject. The construction originates in a way that the user places the cursor over the necessary node, and presses and holds the left mouse button until a connection line is rendered. The definition of the input of the second component occurs using the method of the program's automatic detection of the closest located node to the mouse position. When the program detects components of type “Entity” included in the Entity List, the list of nodes is read and stored through the “Entity” script. Furthermore, if the node has no existing connections and holds the opposite polarity type, the input point of the second component is attached to the given node that is nearest to the mouse position at the given time. An illustration of the automatic detection of the closest node can be seen in Figure 4. The left side of the illustration exemplifies the case in which the node cannot be selected as an input of the second component due to polarity type incompatibility. On the right side, it may be observed the method the program automatically determines the nearest node of the opposite polarity type to the output of the first component.

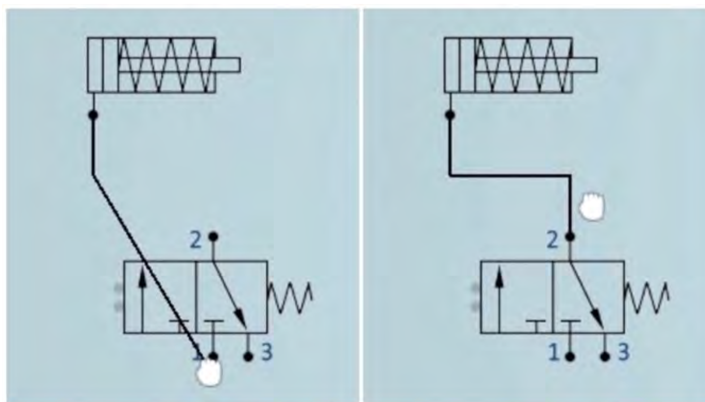

Figure 4. Screen capture of automatic closest node detection

The application allows the removal of already created connections. The “Remove” button is used for this purpose together with a custom script named “ButtonRemoveSelected”. Additionally, a “ResetButton” is added to discard the progress accomplished in schematic composition. The button allows the student to reverse the circuit to its original state at the moment the button is activated.

Verification of the diagram assembly

Each laboratory work implies the fulfillment of the assigned task. In case of correct assembly of the circuit, the transition to the subsequent task is performed. In order to create a list of nodes to be connected, the “SetupInitialConnectionsEditor” script is developed. The list of connections is designed in a way that it stores the identification number of each connection, as well as information about the correspondence of components’ nodes that are connected. In this study, the script is attached to the UI (User Interface) button titled “CheckButton”. In addition to that, two supplementary GameObjects titled “TryAgain” and “Correct” were created. The “TryAgain” GameObject is the child object of the “Canvas Manager” that represents a pop-up window in case of incorrect completion of the assigned task. The “Correct” GameObject involves a pre-recorded educational video that can be observed by the student in order to understand how the circuit is assembled in a real laboratory. Laboratory works should be streamlined, and since the level of complexity changes incrementally, it is rational to supply access to subsequent laboratory work exclusively in case of successful completion of the previous one.

PRELIMINARY ASSESSMENT OF THE COURSE

"Hydraulics and Pneumatics" course syllabus

The "Hydraulics and Pneumatics" course syllabus consists of theoretical and practical activities prior to taking final exams. Initially, the students are provided with necessary theoretical information, thus they are prepared for the laboratory works which are defined as a practical part of the course.

The practical tasks are carried out by groups of students, usually consisting of two or three individuals, and the assignments are passed with the same team throughout the term. The tasks are designed to introduce the students to the different types of pneumatics, electro-pneumatic, and hydraulics provided in the "worksheet". The solutions should be drawn correctly using the standards for circuit diagrams. Consequently, the teacher supervises the students and provides support in the testing of the composed circuits on the designated board. In fact, all necessary components required for each laboratory work's circuit composition are presented in the class. Students are allowed to use various materials during the practice, but they must defend their work when all the exercises are completed along with respective circuit compositions. Defending the practice is an individual activity and each student is assessed on respective skills and knowledge.

Application Testing

Once implemented the application was tested to assess usability, efficiency, and probable future improvements. For this purpose, we prepared a custom questionnaire that included an assessment of aspects such as UI efficiency, usability, and user experience. The questionnaire was used among Bachelor students from autumn 2021 and 2022 Pneumatics and Hydraulics course with gender distribution in 2021: female – 16% and male – 84%, and in 2022: female – 17% and male – 83% from the identical location area, namely, Tallinn, Estonia. Students have performed the laboratory works in the form of gamification experience as a part of the MES0085 "Hydraulics and Pneumatics" course. Consequently, the total number of responses is equal to 62, yet about half of the respondents have never experienced the usage of platforms similar to Unity. The results of the questionnaire revealed that 10 participants could not accomplish all the laboratory works. The prime obstacle was the algorithm of circuit composition, namely in the current version the sequence of components' connection lines is essential, and laboratory work is not marked correct if the schematic is not assembled in ascending order.

The main advantages mentioned by the students in the questionnaire were the following:

- opportunity to execute laboratory works remotely, particularly during the pandemic time;
- instant ascertainment of the schematic correctness;
- link of theory with practice by means of a combination of exercises and educational videos;
- ability to walk around the virtual university;
- smaller size and better performance in comparison with other platforms;
- detailed visualization and intuitive interface for educational purposes.

The general level of satisfaction on a variety of aspects is presented in Figure 5.

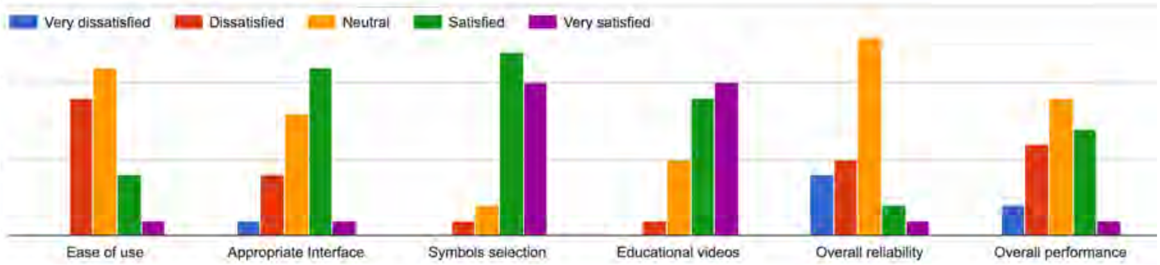

Figure 5: General level of satisfaction

The subject of future development is related mainly to the algorithm of circuit verification which affects such aspects as ease of use, overall reliability as well as performance. In the final analysis, the interface serves as great preparation before the actual laboratory and the gamification experience is overall professional and helpful.

LIMITATIONS OF SOFTWARE AND FUTURE DEVELOPMENT

Currently, the gamification experience is inclusive of one shortcoming which is the verification of a schematic. Generally, the functionality of the gamification experience may be expanded, e.g., on the occasion of hovering over a component located in the inventory, its title may be displayed, which would make it possible to remember the designations of the components more effectively. In addition to that, prompts about what is not correct on the schematic would give the student more insight into the progress. Such prompts may represent notifications that either the components are not selected correctly, or the connection lines are not drawn correctly. As an additional feature, it is possible to add navigation to the educational video that would endow the student with the ability to delve deeper into the subject and be more aware of the circuit composition in the physical lab. Furthermore, by parity of reasoning the laboratory works on Hydraulics can be developed, which would enable students to completely perform laboratory works on the “Hydraulics and Pneumatics” course remotely. Henceforth, the laboratory works on Hydraulics should be included in the project, following the modified and finalized algorithm. Additionally, the preservation of the existing progress should be saved at each withdrawal from the gamification experience in order not to mislay the progress obtained.

CONCLUSION

The present work was designed to transfer the educational process, namely, the conduct of laboratory works on Pneumatics and Electro-Pneumatics, into the form of a virtual gamification experience. To accomplish this task, the work is integrated into the Educational Game Project developed by the Virtual and Augmented Reality Laboratory at Tallinn University of Technology. Originally, the gamification experience was inclusive of a 3D model of the University and a customizable avatar that could move around in a virtual environment. The model of the Pneumatics and Hydraulics laboratory has not yet been built; thus, a student can acquire access to the laboratory works in the Virtual and Augmented Reality Laboratory.

On the occasion of entering the virtual environment, which represents a 2D gamification experience, a user observes the “Main Menu”, which consists of subject selection between Pneumatics and Hydraulics, as well as a return to the 3D laboratory. At the time of subject selection, a list of numbered laboratory works appears, access to which opens exclusively in case the previous task is completed successfully. At the opening of the laboratory work, the student observes the task in text format on the top of the screen, the inventory of symbols, and the designated place for the schematic composition. The objective is to select the necessary components, transfer them to the schematic and build connection lines. For building connection lines, the “UI Connect” Asset is purchased from the Unity Asset Store and applied as a pattern. The connection line represents a Z-shape line, which is determined by 4 control points in order to improve the appearance of the circuit, and each connection line stores information about the nodes between which the connection is created. Laboratory works are developed hereby two UI buttons are located in the left corner of the schematic that allows to destruct connection lines or revert the work to its initial state. In addition to that, two buttons are placed at the bottom, one of which allows the withdrawal of the gamification experience, while the second is utilized to ascertain the composed schematic for correctness. The verification algorithm is that for each laboratory work, a list of correct connections is initially created in the format of connected nodes, and once each connection is built, the student will be able to observe the pre-recorded educational video. The educational videos are inclusive of an illustration of the components that are necessary to assemble a circuit as well as the process of composition and execution. These videos are implemented thereby the student cannot merely compose a theoretical schematic, but also study the construction process in a real laboratory. In case the schematic is not assembled correctly, the user observes a window with the corresponding information. Upon successful completion of the designated task, access to the subsequent laboratory work acquires and the student can revise the progress accomplished.

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BIOGRAPHICAL INFORMATION

Ivanna Sandyk was born in Ukraine on 27th Aug 2000. She is a graduate of Tallinn University of Technology, Tallinn, Estonia with a Bachelor's Degree in Integrated Engineering in 2021. Ivanna used to work at a top tech robotics company. While pursuing a Master's Degree in Design and Technology Futures, Ivanna is also a project engineer in a PRAMECO project funded by European Union. Her primary research topics are gamification as well as educational environments.

Margus Müür was born in Estonia on 26th Jun 1980. He got a Master's Degree in Electrical Drives and Power Electronics at Tallinn University of Technology, Tallinn, Estonia in 2008. Since 2019 Margus has been working as a lecturer in the field of Robotics and Industrial Automation at Tallinn University of Technology. Previously, he had worked as an engineer at Tallinn University of Technology since 2004. He is the primary lecturer in the MES0085 "Hydraulics and Pneumatics" course. M.S. Müür has been the Estonian main expert for WorldSkills and EuroSkills in the field of Mechatronics from 2007 up to 2017.

Vladimir Kuts received his Ph.D. in Mechanical Engineering from Tallinn University of Technology (TalTech) in 2019. From the Year 2017, Dr. Kuts has been Head of the Industrial Virtual and Augmented Reality Laboratory (www.ivar.taltech.ee) in the Department of Mechanical and Industrial Engineering Department of TalTech. Currently, he is a research fellow at the University of Limerick, Ireland. His main research interests include Industrial Digital Twins synchronized with real industrial equipment such as robots and Virtual Reality technologies for human-robot interaction standards validation. Moreover, he is serving as vice-chair of the IEEE Estonian section.

Yevhen Bondarenko was born in Ukraine on 17th March 1998. He graduated from Tallinn University of Technology (TalTech) with a Master's Degree in Computer Systems Engineering in 2021. Since the Autumn of 2021 Yevhen has started his research as a Ph.D. Student in the TalTech Department of Mechanical Engineering. His primary research is dedicated to the development of brain-computer interfaces for controlling digital twins of industrial robots, however, he is also taking an active part in virtual and augmented reality projects aiming to digitalize educational experiences.

Simone Luca Pizzagalli was born in Italy on the 1st of February 1983. He received the B.S. degree in Architecture and Urban planning at Politecnico di Milano, Italy, in 2005 and M.S Degree in Architectural Design at Delft University of Technology, The Netherlands, in 2007. He attended a specialization course in advanced Human Machine interfaces at Politecnico di Milano and the National Research Council of Italy in 2015. He is currently an early-stage researcher and Ph.D. candidate at the Faculty of Mechanical Engineering of Tallinn University of Technology, Estonia. He has a background in planning and user-centered design of assisted and sensorized living environments, focusing on the health and well-being of frail users during daily life activities. Previously active in the implementation of Virtual and Augmented Reality applications aimed at rehabilitation and training at the National Research Council of Italy, he is now focusing on Digital Twin Virtual and Augmented reality interfaces for Human-Robot Interaction.

Tiia Rüütmann was born in Estonia on 15th March 1959. She graduated from Tallinn University of Technology (TalTech) as a Diploma Engineer in the field of Chemical Engineering and Cybernetics in 1982 and received her second MSc degree in chemical engineering at TalTech in 1992. She defended her Ph.D. in Education (with a specialization in engineering pedagogy) at the University of Hradec Králové, Czech Republic in 2007. Since 2001 Tiia has been working as an associate professor and head of the Estonian Centre for Engineering Pedagogy at TalTech. Her field of expertise and research are engineering pedagogy, STEM & university didactics, laboratory didactics, and innovative methodologies. In 2021 she received IEOM Global Engineering Education Award, and she was invited to share her journey to professional success by writing her chapter in a book published by IFEE/GEDC "Rising to the Top". In 2021 she was elected as the president-elect of the International Society for Engineering Pedagogy (IGIP).

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EMBEDDING THE SOCIAL SCIENCES IN ENGINEERING EDUCATION: COLLABORATION WITH A POLITICS DEGREE

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ABSTRACT

This paper reports reflections on the successful adaptation of the CDIO pedagogy to a module offered as part of a Politics and International Relations (IR) degree. CDIO has been highly successful in engineering education, enhancing engagement, attainment, satisfaction and employability, by enabling students to learn engineering *science* through engineering *practice*. The potential to achieve similar outcomes in *political* science, through *political practice*, led the author to develop the Transport: Politics and Society module. With a focus on transport studies, a subject that is naturally interdisciplinary in both academic study and industry practice, this module presents an ideal opportunity for collaboration between engineering and the social sciences. As such, this paper describes the module curriculum, considering content and pedagogy. The paper considers if the format and content of this module could appeal to engineering and social science students alike, enabling engineering graduates to understand and respond to the changing cultural, social *and political* context in which they operate, whilst providing social scientists with invaluable insights into and connection with industry and the workplace. The paper offers this module as a template which, if implemented within engineering programmes, could support the goal of furthering the aim of CDIO 3.0 to develop, embed and enhance the role of the social sciences in engineering education (Malmqvist et al, 2022).

KEYWORDS

Politics; Social science; Sustainability; Transport; Standards 1, 3, 7, 8.

INTRODUCTION

Holzer et al (2016), citing Lyman, suggest that the need for the inclusion of the Social Sciences and Humanities (SSH) in engineering education has long been recognised. However, there is agreement in the literature that, in practice, this idea has, in the main and to date, been ‘more of a politically correct statement than an actual policy’ (Marcone, 2022: 2).

The addition of ‘1.4 Knowledge of Social Sciences and Humanities’ to the CDIO Syllabus v.3.0 (Malmqvist et al, 2022), alongside the acknowledgement of the importance of these disciplines in the revisions to the sustainability and acceleration themes, represents a clear break with this tradition. Syllabus 3.0 represents a step-change in engineering education, by embedding SSH, if not in *policy*, in a close approximation of the same, namely, a set of guiding principles and distinguishing features that should underlie all engineering programmes.

Whilst not prescriptive, the CDIO Syllabus guides the development and delivery of engineering programmes at 196 Universities, across the globe (CDIO.org., Nd). As these programmes adapt to Syllabus 3.0, engineering education will transition from the concept of knowledge as being bounded by the engineering discipline, towards a more holistic, fundamental concept of knowledge and a recognition that knowledge, skills and attitudes from disciplines outside of the engineering sciences are central to preparing students to be effective engineering practitioners, on graduation.

This paper seeks to contribute to the debate on the operationalisation of Syllabus 3.0.

The paper responds to the call issued by Josa and Aguado (2021) for research to (1) examine *how* to incorporate SSH into engineering and (2) to identify which *content* areas – knowledge, skills, attitudes – within the SSH should be prioritised in engineering education. To this end, the paper reflects on the highly successful adaptation of the CDIO pedagogy to a module offered as part of a Politics and International Relations (IR) degree.

With a focus on transport studies, a subject that is naturally interdisciplinary in both academic study and industry practice, the topic of this module presents an ideal opportunity for collaboration between engineering and the social sciences. In response to Josa and Aguado's first call, the paper considers if the *format* of this module may be a suitable template for the incorporation of SSH into engineering. In response to the second, the paper considers the *content* of the module and the extent to which this contributes the *knowledge, skills and attitudes* that should be prioritised in engineering education.

The paper progresses through the following sections. First, a literature review, where the context is presented, considering the rationale for including SSH in engineering education, an overview of potential pedagogic models and an overview of subject content. Next, the Transport: Politics and Society module is presented, including pedagogy, content and outcomes. Discussion of the potential adaptation of the module to engineering education follows. The paper concludes with a consideration of the limitations of this research and suggestions for future studies.

CDIO 3.0: DEVELOPING, EMBEDDING AND ENHANCING THE ROLE OF SOCIAL SCIENCE IN ENGINEERING EDUCATION

Why Include Social Science in Engineering Education?

The primary role of engineers is to analyse, design and build to meet the needs of society (Wang et al, 2022). To be successful in engineering practice, engineers must understand the needs of society. They must connect with the day-to-day life of the community in which their decisions are to be implemented. This requires skills, knowledge and attitudes that are more commonly taught in the social sciences.

Thus, Josa and Aguado state: 'it is indispensable that engineers have knowledge in SSH [social science and humanities] to allow them to make decisions more perceptively, realistically and critically' (2021: 1). Marcone (2022) goes further: 'Without humanities and social sciences disciplines, the recognition of actors and motivations will be poor, generic, and based on prejudgments, focusing on the concrete and evident and limiting the definition of the problem to only a few dimensions.'

Malmqvist et al (2022) highlight the growing importance of the social sciences in engineering education and practice, in light of a rapidly change social context for engineering. The authors note three 'external change drivers', the nature and impact of which can only be fully understood through a deeper understanding of society, to be gained through the social sciences, namely: sustainability; digitalisation; and acceleration. For Ashby and Exter (2019), these drivers are highlighting new problems for engineers, which cannot be solved by one discipline alone but, rather, require an interdisciplinary approach.

Juraku's reflections on nuclear engineering provide perhaps the most compelling case for the integration of social science into engineering.

> Social scientific literacy is not just an "additional" component for nuclear engineers. Rather, it is one of the most "essential" parts of engineering competences and practices... Social-scientific literacy is not a tool to manipulate public sentiment, rejecting their voices. It is a method to listen to it carefully, to find and grasp needs in society, to suggest engineers' proposal to society in humble and sincere manner and to collaborate with other stakeholders than nuclear engineers' 'old friends'. Engineers can take its advantages to make their thoughts and practices more open-minded ones… Return of diversified and independent nuclear engineers is now being waited by society.
> Juraku, 2016: 403-410.

Including Social Sciences: Potential Pedagogic Models

Josa and Aguado (2021) present three potential pedagogic models for including the social sciences in engineering education.

The first and most desirable involves integrating the social sciences into every aspect of engineering education, which the authors term 'transversal' integration. The second is to introduce general social science subjects into the curriculum – for example, including a module on psychology, or sociology, or politics. Juraku et al (2016) describe the PAGES initiative to include the social sciences in nuclear engineering education took this 'addition model', where elements of the social sciences were added to the curriculum, rather than fully integrated and embedded into all aspects of education. Marcone (2022) highlights this approach, using interdisciplinary projects.

The third option identified by Josa and Aguado is to introduce specific social science subjects, for example transport inequality, or environmental justice. Whilst Holzer et al (2016) caution against viewing the social sciences as 'add ons to an already crowded curricula rather than substantially integrated components' (ibid: 4), Josa and Aguado suggest that the current lack of social science knowledge among students and faculty members is likely to prevent this strategy, in the short to medium term.

Including Social Sciences: Content

Finally, it is important to recognise that the social sciences encompasses many disciplines. Marcone (2022) is clear in the content that the social sciences can usefully contribute.

- Soft skills, to enhance the performance of engineers, including communication.
- Providing a social context, a different perspective from which engineers can critique and test their solutions, before implementation. In this sense, the social sciences enter education at the end of product design.
- Providing a social context from which to conceive problems and solutions, fully integrating skills, knowledge and attitudes from the first approach to the last.

This paper suggests a potential module which could be introduced into the engineering curriculum, following the approach to introduce a specific subject, viewed through a social science lens, with social science content fully integrated from concept to operation. It is to this module that this paper now turns.

TRANSPORT: POLITICS AND SOCIETY

Development

CDIO has been highly successful in engineering education at Canterbury Christ Church University (CCCU), enhancing engagement, attainment, satisfaction and employability by enabling students to learn engineering *science* through engineering *practice* (Crawley et al, 2007).

The global success of this active, team-based pedagogy, which accepts, values, includes and encourages all students in the learning community, has led a number of authors to experiment with its adaptation in other disciplines. For example, Malmqvist et al (2016) highlight application in business, chemistry, education, food science and music. Tangkijviwat et al (2018) consider advertising, cinematography, design, media, photography, public relations. Tholler and Rian (2020) review application to digital media, hotel management, health & beauty and Thai traditional medicine courses. Further papers consider CDIO in accounting (En et al, 2022), events management (Ng and Tan, 2022), sustainability (Cheah, 2022) and teacher education (Bang et al., 2022).

The above papers highlight that the CDIO pedagogy has been successfully adapted to non-engineering programmes. However, there are no documented applications to Politics and International Relations (IR). As such, this paper reports the first known adaptation to Politics/IR.

The module aimed to achieve similar outcomes in *political* science, through *political practice*. This inspired the creation of a new module, Transport: Politics and Society, with the Politics and IR framework of degrees.

With a focus on transport studies, a subject that is naturally interdisciplinary in both academic study and industry practice, this module presents an ideal opportunity for collaboration between engineering and the social sciences. As such, this paper now turns to describe the module curriculum, considering content and pedagogy.

Content

The starting premise of the module is that we are a society that needs to move. In the UK and many countries across the globe, we live in a built environment in which physical mobility is both necessary and expected to participate in activities. Economic, planning, social and transport policies have resulted in living environments and activities that are dispersed across large, ever-increasing distances. Our society and culture, our biology and psychology, act to reinforce this mobility dependence in our hypermobile societies.

As a result, to participate in the activities that we need to take part in to be included in the society in which we live – including education, employment, leisure, shopping, social networks – we need to be able to travel, usually by motorised mobility. However, a substantial proportion of us are not able to travel as much as we need to, to take part in the activities that enable us to be included in the society in which we live (Kenyon et al, 2002; Lucas, 2019). This results in *mobility-related social exclusion*.

The link between mobility and social exclusion is well-established. Across the globe[1], studies have confirmed the existence, experience and effects of mobility-related exclusion (MRE):

> The process by which people are prevented from participating in the economic, political and social life of the[ir] community, because of reduced accessibility to opportunities, services and social networks, due in whole or in part to insufficient mobility in a society and environment built around the assumption of high mobility.
> (Kenyon et al, 2002: 210-211)[2].

This is experienced most keenly by those experience disadvantage, inequality and/or exclusion in other ways: children; disabled people; non-drivers; people of colour and other minority ethnic groups; people with a low income; older people; women.

In this sense, some have *too little mobility*, which results in exclusion from activities, including education, employment, healthcare, family and friends, leisure, shopping and other activities that are critical to social development (Kenyon, 2015).

But the solution to the problems caused by too little mobility cannot be to increase mobility, for two key reasons. First, studies suggest that when we increase mobility, we decrease accessibility (Kenyon, 2015), to the extent that mobility and accessibility are described by Ross (2000: 13) as 'the yin and yang of planning'.

Second, increasing mobility is environmentally problematic. Transport is a primary contributor to climate change and environmental harm. Transport accounts for around 16% of global Greenhouse Gas (GHG) emissions (Ritchie et al, 2020). In the UK, approximately a quarter of GHG emissions are estimated to be from the transport sector (DBEIS, 2022). Transport has more far-reaching implications for the environment, causing environmental harms including: airborne particulates and other air pollutants; community bifurcation and isolation; ecosystem damage; land take; noise pollution; resource use; visual pollution; and water pollution.

In this sense, we have *too much mobility*. Increasing mobility to tackle the problem of too little mobility will worsen the problem, in the longer term.

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[1] Knowles (2019) and Lucas (2019) provide an overview of the growth in the field of study since 1993, largely in the UK and USA. To illustrate global reach, in the first six months of 2022 alone, the literature has expanded to include 17 papers on transport and social exclusion, reporting studies from every inhabited continent: Africa (Castro et al, 2022); Asia (Wang et al, 2022); Australasia (Shaw and Tiatia-Seath, 2022); Europe (van Dulman et al., 2022); North America (Cooper and Vanoutrive, 2022); South America (Ospina et al, 2022).
[2] Whilst this definition has been expanded in recent years to include consideration of the unequal impact of negative transport externalities (Kenyon, 2015), this paper focuses on MRE as a *lack of access to participation*, as defined above.

So, what do we do, when policies conflict in this way? Do we tackle exclusion, or environment? Who do we prioritise? Why? Do we prioritise the short term, or the long term? How? These debates lie at the core of the module content and pedagogy, to which this paper now turns.

Pedagogy

The module introduces students to the complexity real world policy practice, through an approximation of a design-build-test project, over ten weeks.

Conceive (weeks 1-4).

Students uncover the problem of transport-related social exclusion first-hand, by taking a walkabout around Canterbury city centre in the UK. Through this mini-ethnography, students observe key features in the urban environment, including a pedestrian crossing, a bus stop, a car park and an underpass. Students are prompted to consider, for example, who they can see and who they can't see in these locations; to count how long pedestrians have to cross at a pedestrian crossing; to feel how welcoming the environments are.

Teamwork begins at this first task: students explore in pairs, matched with someone who has different characteristics to themselves. This helps to illuminate the experience of transport exclusion, but it also encourages students to accept, include and value different perspectives in their 'workplace': an invaluable, real-world, employability skill.

After seeing the problem for themselves, students return to class to discuss their findings. They apply their observations, to conceive the problem of too little mobility as it affects them, or their local community.

All further learning is focused on understanding the specific problem that they would like to resolve. Individualised readings are selected for each student, based on their transport problem. Every student must report back on their reading, every week, to enable other students to learn about the problem of transport exclusion more deeply and theoretically. This develops invaluable professional skills, including communication, confidence, note-taking and reliability; and teamworking builds learning community.

Design (weeks 5-6).

At this stage, students design a potential solution to the problem of too little mobility in their community. They select the decision maker that they need to influence to resolve their problem and present a 5-minute verbal briefing, designed to appeal to their specific decision maker. This is the culmination of their learning about too little mobility and is 50% of their assessment.

Based on government guidance for briefing Ministers (Jary, 2015) and consultations with civil servants and industry, this authentic assessment (Kenyon et al., 2021) is highly employability focused, developing communication skills relevant to all manner of industries, not just in the political sphere, but also business, consultancy, civil service, local government. In combination with the second assessment, it is designed to develop industry-ready graduates, who have built employability skills through this form of work-related experience.

The assessment also shows graduates they belong in the workplace. Graduates are more employable, because they are work-ready; and they are valued and included in the workplace, because they are more able to assimilate into the workplace community.

Implement (weeks 7-10).

It is not possible for students to implement changes to the transport system. To approximate this, students critically reflect upon their proposed solution, by introducing policy conflicts. This, combined with consistent formative feedback on the proposed implementation of their solution, from the tutor and their peers, students consider what may happen if they implemented their proposed solution. First, they consider the potential negative effects of increasing mobility, considering who may be harmed by their proposal – other demographics, the environment – and the negative impact on other policies – economic, health. Second, they consider who may oppose the implementation of their solution and how they may overcome this opposition, through conflict or compromise, to influence implementation.

Operate (assessment).

Finally, students operationalise their learning, by delivering their recommendations in the form of an options and recommendations paper (Jary, 2015), targeted to meet the needs of and to influence the decision-making process of their specific decision-maker.

Through the lens of their transport problem, political decisions are brought to life: the complexity; the compromises; the consequences; the contradictions.

OUTCOMES

The approach has been very successful.

- 100% first-time pass rate for 3 cohorts (equivalent modules: 66%).
- Average mark 70% (equivalent modules: 59%).
- Substantially higher attendance, engagement and attainment, relative to other modules.
- Universal satisfaction (measured in module evaluations).
- All module graduates were in graduate employment/further study 6 months after graduating.

In addition, students' studies have been shared with stakeholders and presented at conferences, highlighting the potential for students' work to have real-world influence and impact. Topics chosen and investigated by students include:

- The impact of lack of transport on Covid-19 uptake in deprived communities;
- Necessary changes to street lighting, to enable active mobility for women;
- A business case for the provision of free transport home from a student nightclub;
- The impact of lack of transport on visitors to a care home;
- The impact of lack of transport on widening participation to Higher Education;
- Measures to enhance safety for LGBTQ+ travellers on public transport.

THE OPPORTUNITY

The success of the TPS module provides proof of concept that the CDIO pedagogy is adaptable to Politics and International Relations courses. It can confidently be asserted that successful adaptation to this social science discipline suggests that adaptation to other social science disciplines, including geography, psychology, sociology and social policy, will also be successful.

Given that this engineering pedagogy works across disciplines, could this social science content work for engineers?

With a focus on transport studies, this module presents an ideal opportunity for collaboration between engineering and the social sciences, to embed social science knowledge, skills and attitudes in engineering education.

Engineers facilitate mobility. Civil engineers design infrastructure; chemical engineers consider fuel technology; mechanical engineers design vehicles. At present, engineers design and build to the needs of society. But what if society's 'needs' are damaging and should change?

Society's demand for mobility is framed as 'need'. As such, engineers who design and build to the needs of society will continue to facilitate greater mobility. However, as discussed above, facilitating this need is environmentally damaging. It is also counter-productive, reducing rather than increasing accessibility in the longer term.

If adapted to engineering education, this module content and pedagogy would introduce engineering students to the complexity of social need. Through the lens of transport, engineering students will be exposed to and will experience the reality of political/Political decision making, learning the contested nature of need, competing interests, conflicting 'solutions'. They will reside in different environments, which reflect the complex web of stakeholders that they will encounter in their professional lives, including the communities impacted by their work and the politicians making decisions.

LIMITATIONS AND NEXT STEPS

The applicability and potential benefits of incorporating this module within engineering education is, at this stage, speculative. Success to date is proven on a single course, with 3 small cohorts (n=c.15 per cohort), at a single University. As such, generalisability to other contexts is not proven.

Next steps in this research are to adapt, implement and evaluate with larger cohorts, in different disciplines and different institutions. With this paper, the author calls for collaborators, willing and able to adapt, implement and evaluate, to expand the evidence-base and further understanding of how to further develop, embed and enhance the role of the social sciences in engineering education, furthering the aim of CDIO 3.0.

CONCLUSION

Syllabus 3.0 represents a step-change in engineering education, by embedding Social Sciences and the Humanities in the guiding principles and distinguishing features that should underlie all engineering programmes. This paper has sought to contribute to the debate on the operationalisation of Syllabus 3.0.

The paper has highlighted success in adapting the CDIO pedagogy to a module on a Politics and International Relations course. With a focus on transport studies, a subject that is naturally interdisciplinary in both academic study and industry practice, this module presents an ideal opportunity for collaboration between engineering and the social sciences.

The paper suggests that this module could be used as a template which, if implemented within engineering programmes, could support the goal of furthering the aim of CDIO 3.0. The paper offers proof of concept that the module curriculum could be effective and calls for collaboration in a range of engineering courses and settings, to further this research agenda.

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BIOGRAPHICAL INFORMATION

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BLENDED LABORATORIES FOR JOINING TECHNOLOGY

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ABSTRACT

Laboratory training is an essential part of most Engineering Education programs and amplified by the Covid-19 crisis, educational institutions are increasingly exploring blended and online laboratories as an alternative or complement to pure on-side learning environments. In this paper, we report on the (re-) design, implementation and evaluation of a blended laboratory concept in joining technology. The laboratory consists of three interlinked pillars and builds conceptually on the flipped classroom approach. We evaluate student learning and satisfaction as well as teacher experiences in the new learning design based on student evaluations and performance data as well as teacher reflections. The results show that the new laboratory improved the average grade of students by 12% compared to the traditional set-up, which we attribute to the increase in active learning. Students also report high satisfaction with the new format and appreciate the flexibility and accessibility of the online learning materials. Qualitative analysis indicates, however, that successful participation in the flipped format is coupled to high degree of self-regulated learning skills. Further, teachers partly had difficulties to ensure active participation in the synchronous online sessions. Despite these issues, we conclude that the presented flipped laboratory concept is an excellent format to combine the advantages of online learning with the hands-on experience of physical laboratory work. By utilizing the benefits of online learning, this format reduces the time students spend passively listening to lectures and more than doubles the time spent on active learning and practice.

KEYWORDS

Online laboratories, Flipped classroom, Online learning, Blended learning, Robotic Welding Standards 5, 6, 8

INTRODUCTION

Laboratory training is an important part of engineering education programs, as it allows students to acquire practical skills and knowledge through exploration, experimentation, and reflection in an inquiry-based learning environment (Hofstein & Lunetta, 2004) including analysis, creativity, and teamwork skills (Mohammed, et al., 2020). Traditional laboratory environments have been shown to have numerous benefits for students, including improved understanding of course material and enhanced problem-solving abilities. However, these environments also come with their own set of challenges, such as high costs, limited access and safety risks. As a result, and amplified by the Covid-19 crisis, educational institutions have been turning to blended and online laboratories as alternatives or supplements to in-person learning environments (Graham, 2018; 2022). In this paper, we present the design, implementation, and evaluation of a blended laboratory concept in joining technology, an interdisciplinary course module that incorporates elements of materials science, electrical engineering and construction. Pedagogically, the laboratory is based on the flipped classroom approach, where students prepare at home for more active learning in the on-site laboratories (Stöhr & Adawi, 2018). The learning design consists of three pillars: (1) asynchronous online learning activities, (2) synchronous digital live demonstrations, and (3) on-site presence laboratories featuring augmented reality-based and real welding exercises. Based on data from student assessments and evaluations, we examine the benefits and challenges of the new learning design in comparison to traditional laboratories.

STATE OF THE ART

Online laboratories are a type of e-learning tool that allows-students to perform experiments and simulations remotely using real or simulated equipment. According to Chen et al. (2010), one can distinguish two basic approaches: remote labs and virtual labs. Remote labs involve real equipment that are controlled remotely through the internet using predefined gateways (directly or via a livestreamed instructor in the laboratory). The experiments can be followed live via video transmission and real measured values would be determined (Burdinski & Schifftler-Weinle, 2020). Virtual labs refer to simulated lab environments based on software and streaming approaches. A number of studies have been conducted on the advantages and disadvantages of these online lab alternatives, as well as their effect on student learning. One of the main benefits of online laboratories is that they can provide learners with access to a wide range of equipment and resources that may not be available in their local environment, which is especially valuable for learners in disadvantaged or underserved areas (Correia et al., 2018). Similarly, Nedic et al. (2003) and Post et al. (2019) found that remote and virtual labs are low-cost alternatives, providing flexibility and accessibility for students. Lynch and Ghergulescu (2017) and Potkonjak et al. (2016) noted that remote and virtual labs are resistant to damage and have simplified maintenance of lab facilities. Several studies have demonstrated the effectiveness of online laboratories in promoting learning. For example, a study by Rios and colleagues (2017) found that online laboratories can enhance learners' understanding of scientific concepts and improve their problem-solving skills. Correia et al. (2018) found that online laboratories can promote the development of critical thinking skills and increase learner engagement. Bartocci et al. (2011) found that virtual labs can enable students to participate in inquiry-based learning to formulate and examine hypotheses, and West and Veenstra (2012) found that students appreciate the ability to repeat experiments at their own pace.

However, Lynch and Ghergulescu (2017) and Potkonjak et al. (2016) also noted that virtual laboratories lack a real-life feel and can lead to oversimplifications if designed or implemented incorrectly. Students work only with a model representation of the real experiment (Burdinski & Schifftler-Weinle, 2020) and miss the experience of experimenting on real machines. The measured values can also differ greatly from real values and data generated in virtual labs tends to lack variation (Lewis, 2014). Sources of error from the real laboratory are eliminated so that students do not learn how to deal with incorrect measured values. Another challenge of online laboratories is the need for learners to have access to appropriate technology and internet connectivity (Correia et al., 2018). Finally, the switch from face-to-face to online laboratories is proving to be difficult for teachers. In a recent survey (Krämer & Hammerich, 2020), 80% of the lecturers stated that they perceive practical tests and experiments to be particularly limited by online teaching. In addition, 17% of them feared that most students will be significantly behind in learning

Overall, studies have shown that remote and virtual labs can provide equal or better learning outcomes for students compared to traditional labs (Brinson, 2015; Post et al., 2019). However, the design of online laboratories can have a significant impact on learning outcomes. Effective online laboratories should be interactive and provide learners with opportunities for experimentation and exploration (Rios et al., 2017). They should also include appropriate guidance and support, such as feedback and instructional materials, to help learners navigate the learning process (Correia et al., 2018). It is also important to note that there are little concepts or studies in the literature for the digitization of laboratories with large and dangerous equipment such as joining technology. The transfer of concepts (such as simple circuits or experiments), especially from the field of physics, electrics, or computer science to laboratories such as manufacturing technology, forming technology, joining technology, etc. is not easily possible. Thus, there is a need for further research to understand students' experiences using online and blended labs and to provide design recommendations for creating a more positive learning environment in this field.

CONTEXT: THE PROBLEM WITH THE JOINING TECHNOLOGY LABORATORY

Joining technology as an example for laboratories with heavy and dangerous equipment, is an interdisciplinary module that based on competencies from subjects such as materials science, electrical engineering, and construction. The laboratory units contribute to the application and deepening of the theory with practical exercises to provide a better understanding about different processes of joining. At the end of the module, students should be able to distinguish and evaluate different joining and cutting processes, explain how they work and, to a certain extent, apply them themselves. The entire module is worth five ECTS points. Due to the number of students and the limited resources, practical knowledge is not imparted to the same quality for all participants. As illustrated in Figure 1, a laboratory group consists of up to 15 students who are expected to observe, listen and understand the interaction between process, handling and types of errors within practical demonstrations.

During the laboratory exercises, students and instructors are confronted with challenges due to smoke gases, sparks, noise, obstructed vision, noise and acoustics etc. In particular, the visual impairment and the poor acoustics are main reasons for the inadequate transfer of knowledge from instructors to students. Due to the size of the group, the students cannot fully experience the practical demonstration as only the few students who have a clear view. A welding mirror or a welding helmet must be worn during welding to protect the eyes. As a result, the arc can be observed without endangering the eyes, however phenomena such as the distance between the torch and base material as well as the torch guidance are not sufficiently recognizable. The environment would be blurred by the evaporated smoke gas during welding. This means that important explanations can only be partially observed by the students. To carry out the laboratory exercises, the ventilation system must be switched on to evacuate the smoke gases. The resulting background noise and the noises that occur during welding make it difficult to understand the explanations properly, leading to insufficient transfer of knowledge to students. The instructor explains the important aspects while welding and wears a welding helmet for eye protection. The instructor's voice is muffled by the helmet and is overlaid by the background noise. Accordingly, only the very attentive students in the immediate vicinity of the instructor can pick up all the important information. In addition to the difficulties in the practical transfer of knowledge, students also had demands for improvement. According to the surveys from 2018 and 2019, 89% of the students wanted to increase the proportion of self-welding. They also expressed that the theoretical part of the laboratories should be reduced to a minimum, since those contents were explained in the lectures. However, despite those challenges, laboratories are elementary components of applied instructing and are highly valued by students.

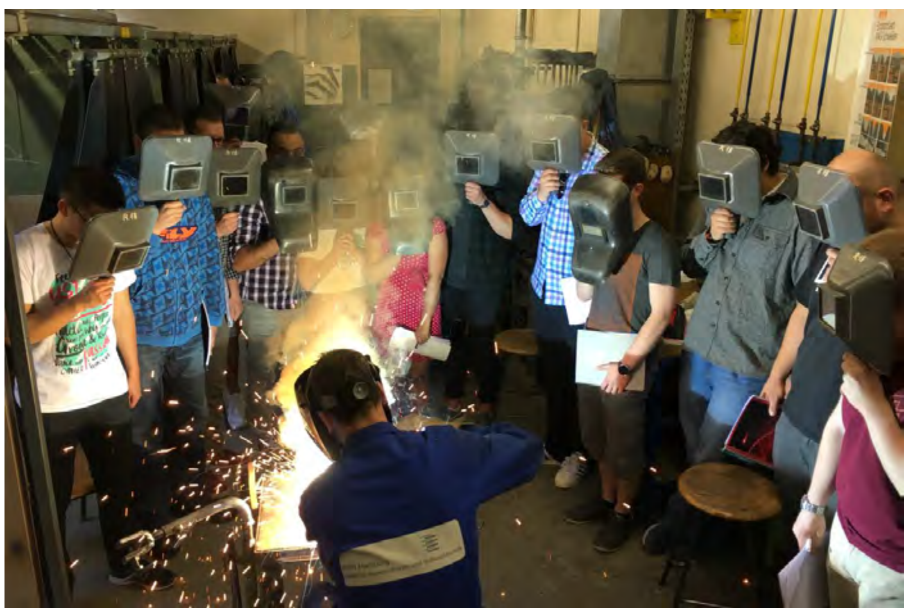

Figure 1: A typical laboratory for welding

DESIGNING A NEW LABORATORY FORMAT

The pandemic situation in the summer semester of 2020 required a fundamental redesign of the concept of the laboratories for joining technology. As part of student projects, an overall concept was developed to optimize the transfer of knowledge and overcome the above-mentioned challenges and restrictions. Learning outcomes and credits thereby remained the same as in the traditional format. Different formats such as explanatory videos, virtual tours, augmented reality, and digital live presentations were combined into an overall concept for the laboratories consisting of the following interlinked pillars:

1. Virtual laboratories + learning outcome online tests
2. Online presence laboratories + protocol + learning outcome online tests
3. On-site presence laboratories: Welding using augmented reality and real welding

After as short description of the technical set-up, we will describe the three pillars in more detail.

Technical set-up

For the first and second pillar, a trained laboratory staff is needed to use and integrate cameras and microphones. Moreover, the cameras and microphones used must be suitable for the special environment (brightness, noise, smoke, heat, sparks, etc.) of welding. In particular, it is revealed that a self-focusing camera is the most problematic one during welding, as the videos became unusable due to the automatic focusing. On the other hand, fixed focus cameras are not precise enough when close-up shots had to be shown. The brightness of the welding process is another challenge to recode digital laboratory materials (offline or online videos). Using a filter would reduce the brightness and make the welding process watchable, however, the overall view of the welding process is thereby impaired or hindered.

As already explained, welding by-products such as smoke and radiation as well as brightness require the use of a welding helmet. This protects the instructor during the practical demonstration. In addition, the fume extraction must be switched on in order to discharge the welding gases. Both the welding helmet and the smoke evacuation system prevent a sound transmission. In the primary recordings, the instructor's explanations and the characteristic noises during welding were drowned out by the fume extraction system. Also, the type of microphone influences the sound quality of recorded videos. Using a wireless microphone has the advantage of free moving however the disadvantage of sound missing or delay sound transmission. As a result of the first study there was a need for three cameras and two microphones (both equipped with surrounding noise cancelling) to better capture the real welding atmosphere. For the arrangement of the online presence laboratories, a software was necessary to integrate different perspective on one monitor. The freeware software OBS was chosen since it was already used for the theoretical lectures.

The equipment used to produce the videos both for virtual and online presence laboratories are schematically depicted in Figure 2. The best quality was produced by having two lecturers (nr. 1 and 2. in Figure 2). The main lecturer (1) performs the welding and explains issues during welding. Nr. 2 is the assistant lecturer who takes care of the Open Broadcaster Software (OBS) (nr. 7). The assistant is also responsible for the arrangement of the cameras, their repositioning, if necessary, as well as observing the chat monitor. To assure an acceptable video and sound quality, there is a need of using three cameras (nr. 4, 5 and 6). The sound is transmitted using a microphone in the helmet of the main lecturer. This way, the explanations made are clearly understandable. The welding sound was captured by a microphone attached to camera nr. 4. This microphone with a surrounding noise-canceling eliminated most of the disturbing sound of the fume extraction system.

The set up shown in Figure 2 was essential for online presence laboratories, since the students joining the laboratory from home had to clearly see and understand the correlation of the welding appearance and set parameter. The chat function enables an interactive laboratory. For the execution of the virtual laboratories the same set up was used.

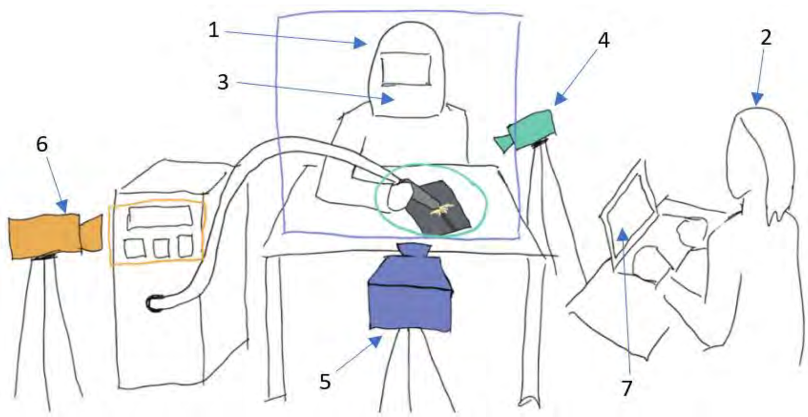

Figure 2: Schematic set up of a welding laboratory

Within the laboratories, different key processes of joining are demonstrated and explained. After a certain training of the laboratory staff first digital laboratories presented in June 2020. In the following, the content of the different laboratory types (interlinked pillars) is explained.

Pillar 1: Virtual laboratories

The virtual laboratories have been designed considering parts of flipped lab concept, where the theoretical lecturing part is moved outside the classroom to free more room for active learning (Stöhr & Adawi, 2018). The virtual laboratories are created as self-study module and include pre-selected video material and short texts. Following best practices of video production in online education (e.g., Guo et al., 2014), the basics of each process are explained in short videos with a length of three to five minutes. The short descriptions enable students a better understanding of the process. For each of the above-mentioned processes, explanatory videos have to be produced which is a time-consuming step. Therefore, as a first approach, available videos on YouTube had been evaluated. These videos and explanatory texts are presented to the students using a Moodle platform of the university. The so-called Emil-Room contains all necessary information for the students for each individual module. Therefore, the necessary files for the virtual laboratories are uploaded in the Emil-Room, available for registered students. The total working load of this part is about two to four hours for the students. The pillar of virtual laboratories is completed through a successful multiple-choice test and students are provided with test functions as a gate to pass on to the second pillar of the laboratory event.

Pillar 2: Online presence laboratories

This type of laboratory is designed as a live stream with live interacting students from home. Students are asked to suggest the welding parameters and the main lecturer demonstrates the welding and discusses visible correlations with the students. The main lecturer emphasizes certain phenomena of welding such as arc type or formation of silicon nitride, sparks etc. The main aim of this laboratory with a total working hour of 10 is to evaluate meaningful parameters together with the students and demonstrate the result of those parameters. To do so, each semester other/new parameters will be used to produce welds for the live discussion. The live discussion part is moderated by the assistant lecturer as depicted in figure 3.

Having the dialogue with students is the essential part of these laboratories. Figure 3 shows the application of the laboratory after performing live welding. The main lecturer asks questions, explains, and discusses the results. The assistant lecturer keeps the overview and moderates the session. This pillar is successfully passed when students upload their protocols and pass an online test.

Pillar 3: On-site presence laboratories

The on-site presence laboratory is concepted to allow students to do virtual and real welding on their own and experience topics like safety, machinery, and handling. It is to notice the weight of the torch to understand how to set parameters and to understand that the quality of a weld is very dependent on the mood, fatigue state and so on of the welder. These laboratories represent a further development of the classic laboratories. Since the classic laboratories were appreciated by students, it was decided to keep on-site laboratories in a way that students enter and start welding after a short introduction on how to use the machines. These laboratories have a working load of two hours. The past on-site presence laboratories allowed the students only to do Manual Metal Arc (MMA) welding. The newly developed concept expands not only the time students can practically weld on their own, but also give them the experience to do Metal Shielding Gas (MSG) welding as well. The new concept that also considered suggestions of the students, was applied in winter semester 2021 and summer semester 2022 to students of the module joining technology, enabling the authors to present first experiences from student and teacher perspective.

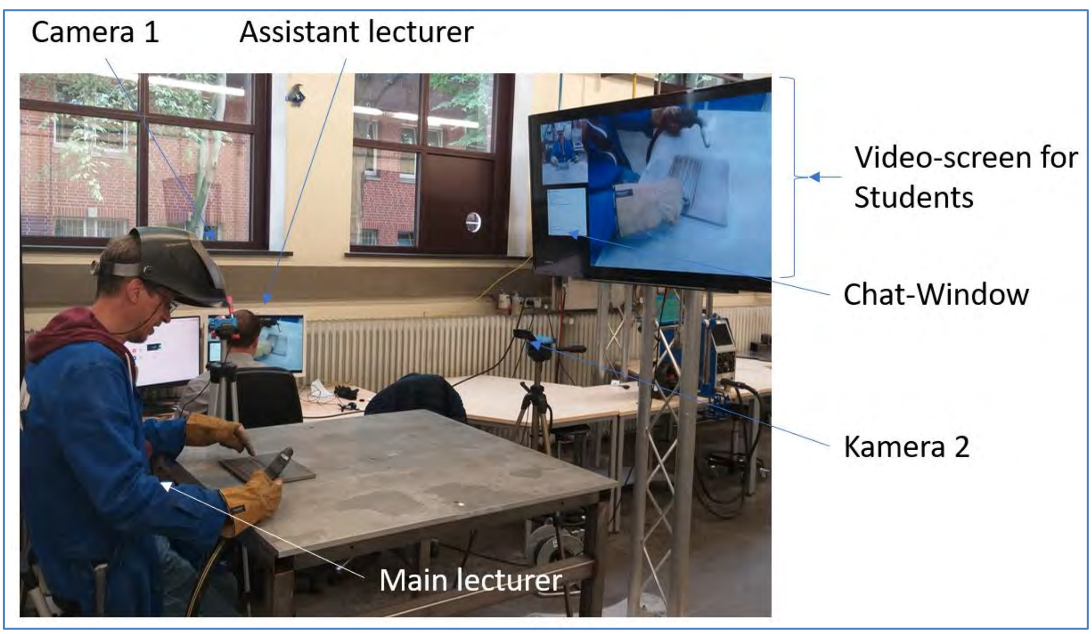

Figure 3: Schematic set up of a welding laboratory

Overall, the development of this concepts requires substantial effort prior to the course and must be started at least half a year before implementation. During the course, however, teaching effort is reduced by ca 60% over the course of the semester compared to the prior set up. This is mainly because the need to repeat a large amount of the content for three groups was reduced to only one group. Further, the virtual laboratories - though effort intensive in their development - require little to no teaching effort during the course. The implementation of the online presence laboratories takes about twice the time, as two employees are needed for the actual demonstration and operating the computer, cameras, and chat. The workload for the on-site presence laboratories remains about the same as in the previous format.

METHOD

As the purpose of this study is to present the design and evaluation of a blended laboratory, a case study approach (Yin, 1994), was employed. A case study is a research method that involves an in-depth examination of a specific situation or event, such as a person, group, organization, community, or phenomenon. It is a way of gaining insights into complex social and behavioral phenomena by studying them in their natural setting. Case studies are an appropriate research method when the goal is to understand how or why a phenomenon occurs in a particular context. It can involve the collection of data through various methods such as interviews, observations, and document analysis, and the data is usually analyzed in a holistic and interpretive manner (Merriam, 1998).

In this study, the authors collected quantitative and qualitative data from students through end of course evaluations that asked students to rate their understanding of the material and their satisfaction with the instruction, performance data in form of exam results. The quantitative data was analyzed using descriptive statistics (e.g., Cleff, 2019). The data from the teacher reflections and student evaluations were analyzed via inductive thematic analysis (Braun and Clarke, 2012) to identify patterns and common themes in the feedback as well as areas of strengths and weaknesses of the new laboratory design. Together, the data was interpreted to identify areas of improvement for instruction and assessment, and to develop recommendations for future instruction.

RESULTS

Student activity

The joining technology module consists of 3 hours lectures per week and one hour laboratory work. Thus, for the whole term, 18 hours of laboratory work must be completed by the students. Compared to traditional laboratories (before 2019) the practical time of self-welding was doubled. The theoretical part of the laboratories was converted into self-study. This way students were enabled to intensify more time for demonstration experiments and discussion with laboratory staff as well as gaining self-welding experience (see Figure 4). However, in practice, the hoped-for active participation in the online live laboratories did not materialize, as most of students were logged in but did not participate in the chat.

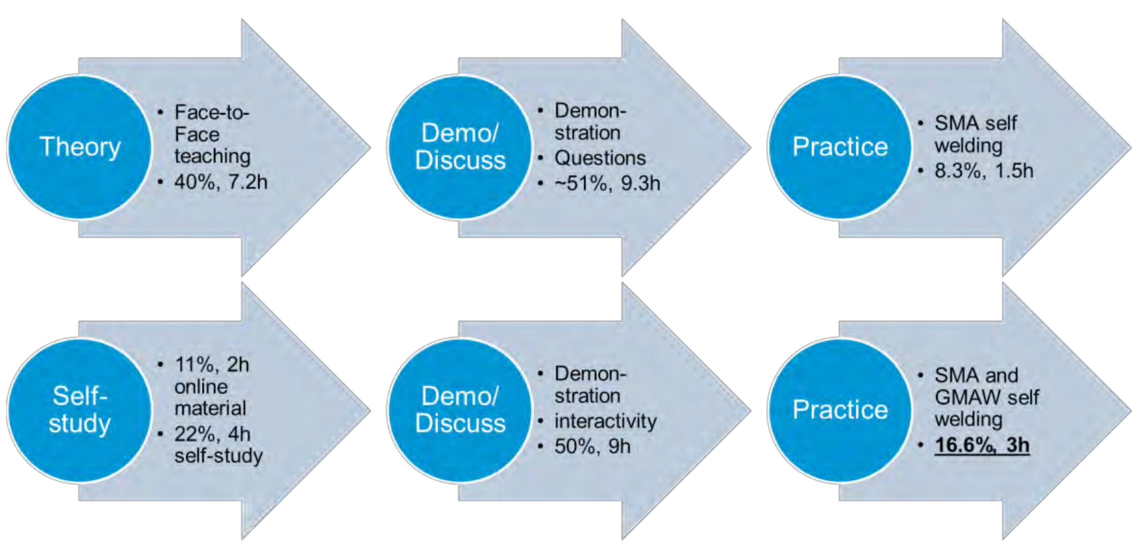

Figure 4: Conventional laboratory activities (top) compared to the new design (bottom)

Student performance

The assessment showed an overall improvement in the grades in the laboratory tests after the practice lab, which is shown in Table 1. The average grade improved from 2.3 to 1.7 (note that in the German grading system, lower grades indicate better learner performance, and it ranges from 1: very good to 5: failed). This is an improvement by 12% compared to the traditional laboratory.

Table 1. Graded laboratory test results

Semester	Number of students	Average grade
Summer 2019	71	~ 2.3
Summer 2021	66	~ 1.7

Student satisfaction

Student feedback on the new developed set-up is overall very good as indicated by the average agreements to statements about various aspects of the course design (see Figure 5). All items scored, in average, above 4 which confirms the attractiveness of the new learning design for most students. The benefits of this new learning design were also highlighted by students through qualitative feedback, with several key themes emerging. One of the most commonly mentioned benefits was the ability to participate in laboratory activities from the comfort of their own homes. This was seen as a major advantage, as it allowed students to engage in practical welding activities without the need for physical attendance at the university. Additionally, students noted the high video and streaming quality of the online resources, which improved their overall learning experience. Another benefit that was frequently mentioned by students was the improved opportunities for discussion and collaboration. The online format allowed for deeper and more technical and valuable discussions, as well as more time for self-welding and practical welding activities. Additionally, the lab-on-demand videos were always accessible, which increased flexibility in terms of time and location for students.

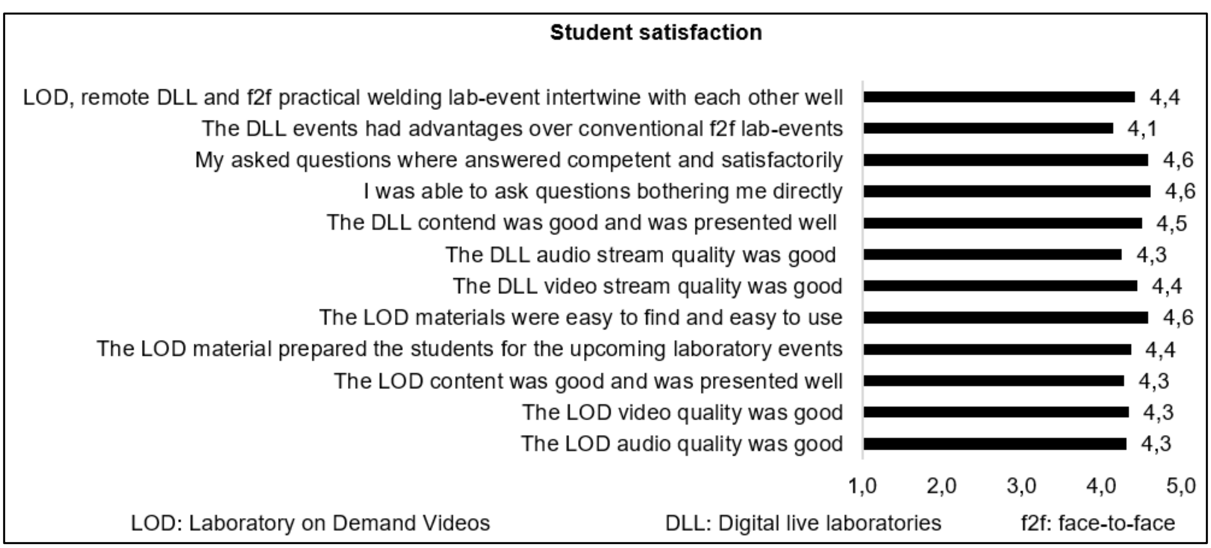

Figure 5. Student satisfaction with the new laboratory design (1…fully disagree – 5 fully agree)

However, it is important to note that the new learning design also had some drawbacks. Some students reported minor technical client site problems, such as poor internet connections, which hindered their ability to access the online resources. Additionally, some students felt that the lack of "just in time" possibility to ask questions during the lab-on-demand part was a disadvantage. The online format also made it challenging to build a sense of community among students. Finally, a part of the students also stressed the importance of using subtitles in addition to spoken explanations, to helped understand the content more easily.

DISCUSSION

This study was set out to describe and evaluate the shift towards a new learning design for laboratories in welding that utilizes educational technology and a flipped classroom pedagogy. From the student assessment and evaluation, we see that an improvement of learning outcomes was achieved, which we attribute to several factors. First, the larger amount of practice time implied an increase in active learning for the students. The students learned practical welding skills in both MSG and MMA welding which was also really appreciated by the students. Further, quality, flexibility and accessibility of the lectures and demonstrations were increased. The asynchronously provided theoretical content for self-study can be accessed and practiced by the students at their own discretion and pace. The students learned theoretical basics of welding and cutting technologies and processes which were shown by the lecturers in the online live laboratory events so students were not only told the knowledge, but they were also given examples to look at, to hear the processes and to discuss. All laboratories were recorded, and the results were made available to the students, making recapping of the content easier. The online presence laboratories showed individual welding characteristics, where the conveyance of the course content was not negatively influenced by the development of smoke gases, the noise level, or the number of group participants. Together, this set-up provided students with a better learning experience, which is also demonstrated by the evaluation results, stating that students prefer Digital Live Laboratories format over the traditional format (score 4.1). This is a somewhat surprising as students, while acknowledging the benefits of online learning, generally tend to prefer the “real thing” (e.g. Olesen et al., 2022).

There were, however, also a number of barriers that need to be addressed in the future. First, as typical for flipped learning designs, the asynchronous self-study part puts high demands on the students’ self-organization and self-regulation of learning (Stöhr et al., 2020), which was not the case for all students. Further, it is more difficult in an online setup to engage students actively via chat and the inadequate active participation of the students can frustrate the instructor. This can be explained by the increased transactional distance as the “*psychological and communication space to be crossed, a space for potential misunderstanding between the inputs of instructor and those of the learner*” (Moore, 1993, 22), compared to in-class teaching and which require measures to overcome in online learning (see Stöhr et al., 2020). Further, from a teacher perspective, the special condition of welding made it difficult for the lecturer to provide digital content. Creating those contents was a time-consuming effort and required suitable equipment that mostly was not available at first but is crucial for the success of the online learning experience. This was demonstrated through the issues with the first developed videos that had poor sound and picture quality. As a result, students did not watch the videos and both students and the teacher became frustrated. Thus, it is important to obtain the suitable equipment (cameras and microphones) beforehand and to carry out appropriate test recordings with smaller groups of students. This also implies proper training for instructors to be able to use “new” media that they have no prior experience with.

CONCLUSIONS

In recent years, the use of technology in education has been on the rise, with an increasing number of universities and institutions turning to online and blended learning methods to enhance the student experience. One such example is the implementation of a new learning design in a welding course in higher education, which utilized online resources such as laboratory simulations and lab-on-demand videos to supplement traditional in-person laboratory sessions to overcome drawbacks of traditional laboratory welding practice, where students and instructors are confronted with challenges due to smoke gases, sparks, obstructed vision, noise and acoustics etc. Overall, the new learning design implemented in the welding course at the university demonstrated a number of benefits, such as increased flexibility and improved opportunities for discussion and collaboration. However, it is also important to note that there were some drawbacks, such as technical difficulties and challenges in building a sense of community among students. The authors conclude that replacement of laboratories solely with digital content is not expedient for joining technology. Providing the videos or animations does not replace the dialogues with the instructors. In addition, it is important that particularly in the case of dangerous production activities such as welding technology, the students themselves develop a feeling for the dangers (smoke, radiation, noise, combustion, etc.) as well as for the job stress on employees (welders). This experience can only be conveyed through presence laboratories. The concept tested here shows a balanced mixture of digital events and laboratories in presence with positive results with regard to student satisfaction and learning. In the future, more contents for the virtual laboratories will be produced. Furthermore, a new method has to be developed to increase the active participation of the students. While our study provides some initial insights, further comparative research is needed to confirm the transferability of our findings to other programs and learning contexts. This may include meta-studies and comparisons of multiple single-case studies.

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BIOGRAPHICAL INFORMATION

Shahram Sheikhi is Professor of Materials Science and Joining Technology since 2014. His background is welding of aluminium and the analysis of its formability. He has studied in University of Wuppertal and received his PHD 2006 in the field of production technology from the University Essen-Duisburg. Currently he is heading the laboratory of welding and is the head of a research and transfer centre (FTZ3i). His research topics include automation in joining technology, the use of robots in surface technology, 3D printing and sustainable production. He has introduced digitalization into teaching and developed new teaching formats for his classes in joining and material's science.

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CDIO AND COMPETENCY-BASED LEARNING APPROACHES APPLIED TOGETHER TO MILITARY ENGINEERING EDUCATION

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ABSTRACT

The CDIO consists of a curricular approach customized to the reality of engineering undergraduate courses, considering several specialties, and which was built from a large-scale survey of knowledge, skills and psychological characteristics currently required of the engineer. On the other hand, competency-based learning is a methodology that is used in several courses in the Brazilian Army, which connects different areas of knowledge and, instead of focusing on theory, aims to prepare for a professional action that mobilizes knowledge, resources, attitudes, values, and skills in specific situations in professional life. In this methodology, students have access to a curriculum made up of integrated modules to develop new capacities, practical, technical, cognitive, and socio-emotional skills and to teaching based on problem situations. In this context, it is possible to identify the synergy between these two approaches. It was precisely the convergence between these two curriculum construction systems that made it possible to develop a hybrid methodology at the Military Institute of Engineering (IME), which integrated the CDIO and the Competency-based Learning methodologies used by the Brazilian Army. It should be noted that another challenge is to keep this hybrid methodology in line with the Curriculum Guidelines for engineering education in Brazil. Therefore, this paper makes a comparison between the main concepts and the sequence of actions necessary to build an innovative curriculum, contemplating both approaches, which can facilitate the understanding of the reform currently underway at this Institute.

KEYWORDS

Constructive alignment, academic implementation, innovation. Standards: 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

Competency-based learning has marked the recent evolution of professional education due to the predominance of situations involving complexity and uncertainty in the engineering work environment, which requires an undergraduate course that provides an interdisciplinary character and the development of teamwork skills. Thus, it is not enough for engineering professionals to have a solid scientific base, although it continues to be essential. It is also necessary for the engineer to integrate theory into professional practice through effective knowledge transfer strategies, in concrete situations in the world of work.

In this direction, from the 1990s onwards, the CDIO Initiative proposes a teaching methodology based on competences that involves a systematic curriculum construction and suggests a set of didactic procedures, based on the mapping of the so-called macro competences of the engineer – conceiving, designing, implement and operate – to which a repertoire of skills, knowledge and attitudes is linked. This mapping was carried out in the job market, on a large scale, considering the professional reality of several countries.

In Brazil, competence learning in the engineering area was initially regulated through the National Curriculum Guidelines (NCGs) for undergraduate engineering courses in 2002 (Brazil, 2002), which aimed to train professionals in accordance with the current needs of society and the labour market, by determining an engineer's profile based on a humanistic, interdisciplinary, and reflective approach. This approach was intensified in 2019, when the Brazilian Ministry of Education established the new NCGs for the undergraduate courses in engineering (Brazil, 2019b), and which required the explicit formulation of systematic curriculum planning, didactic and evaluation procedures, both within the scope of the Course Pedagogical Project and in the curricular documents of the engineering courses.

In this context, in order to help engineering courses in Brazil and Latin America, it is considered important to describe the pedagogical tools that are currently being introduced at the Military Institute of Engineering to meet the requirements of the new NCGs in this area, explaining the logic of construction, invention and recreation, and the synthesis of existing methodologies, analysing how they are adapted to each field of engineering, the organizational culture of the engineering school and the characteristics of teachers and students.

In this perspective, this work analyses the creation of the curriculum construction methodology of the IME, which incorporated elements of the CDIO, of the new NCGs for the Brazilian graduation courses in engineering and of the competency-based learning of the Brazilian Army, from a collective process of customization carried out through a partnership between the Department of Science and Technology (DCT) of the Brazilian Army and the IME, based on the management of a group of implanters from the IME, formed by five leading professors called the G-5, a team composed of twenty professors who coordinate the ten undergraduate courses at the IME, called the G-20, and two pedagogical advisors, one from the DCT and one from the IME.

Therefore, the IME's curriculum construction methodology assimilated concepts and procedures from three approaches: the CDIO, the new guidelines for the Engineering course and the competency-based learning of the Brazilian Army. They are methodologies that provide important concepts about the act of teaching and learning, suggesting sequences of procedures for constructing or diagnosing curricula, as well as didactic activities and learning assessment.

APPROACHES TO CURRICULUM FRAMEWORK DEVELOPMENT

CDIO Approach

The CDIO approach was developed by the Department of Aeronautics and Astronautics Massachusetts Institute of Technology (CDIO, 2022), in response to two demands: on the one hand, an exponential increase in technical knowledge in engineering and related areas; on the other hand, the perception that engineers should have diverse attributes and skills of a personal and interpersonal nature, which would allow their participation in work teams to produce products and systems.

To develop the CDIO Syllabus (Crawley, Malmqvist, Brodeur, Östlund, & Edström, 2014), which outlines the attributes and desirable characteristics of the engineer, the CDIO Initiative carried out a broad mapping of the knowledge, skills, and abilities of engineers, in various fields of engineering and in many countries.

Thus, the CDIO Syllabus establishes the main professional requirements for the exercise of the activity that must be considered by engineering courses, considering the norms and guidelines of professional engineering practice and other aspects considered relevant by other professionals in the field. It is subject to customization in the most diverse contexts of professional action and can be made more flexible based on different organizational cultures, making explicit the levels of excellence in carrying out tasks. It is also possible to use the Syllabus in personnel selection and personnel training processes in companies and professional training in higher education courses in engineering. The Syllabus contains wide-ranging professional activities: conceive, design, implement and operate products and systems.

The Syllabus is also used as a starting point to develop learning outcomes and build the school curriculum, highlighting the role of engineering sciences and scientific research in the area. Includes the following components: technical knowledge and cognitive skills; personal and professional skills; and interpersonal skills.

Among the individual's skills, there are skills of a professional nature, such as problem solving, scientific discovery and systemic thinking, as well as oral and written communication, use of information and communication technologies, in addition to those related to professional ethical behaviour. The Syllabus also includes some characteristics of the person, such as initiative and perseverance, creative and critical thinking, intellectual curiosity, self-improvement, and teamwork attitudes.

For curriculum implementation, the CDIO Initiative suggests the CDIO Standard as best practice (Ulloa, Villegas, Céspedes, & Ramírez, 2014). The CDIO Standard involves preparing the course to achieve the learning outcomes by adapting appropriate teaching-learning practices, using labs, and assessing learning.

New Brazilian Curriculum Guidelines for engineering education (NCGs)

Coordinated by the National Council of Education and composed of specialists from the academic, professional and business sectors with knowledge in the axes of the guidelines, the new NCGs were built from five thematic subcommittees, guided by the general coordination, in order to produce a support document (BRAZIL , 2019a). One of the objectives is to reduce school dropout, which is common in undergraduate engineering courses in Brazil, proposing a new teaching-learning model for teaching engineering, different from the old model of lectures and solving book exercises, considered, in part, as responsible for the low intellectual performance of students.

The new NCGs is a law document for engineering education based on the well-known KSA - knowledge, skills, and attitudes - that constitute the competencies for the future engineer. There is also evidence of explicit adherence to an approach centered on active learning, which consider the student as the protagonist of the teaching-learning process (CNI et al., 2020).

The main objective of this document is to promote a closer articulation of engineering courses with the market, with the productive segments and with professional councils, which requires the elaboration of flexible study programs, in permanent evolution, permeated by integration activities. In short, a curriculum that manages to reproduce the real working conditions of the engineer, which is not the case of traditional curricula, of a theoretical nature, and of compartmentalized knowledge.

In fact, the new NCGs invert the relationship between content and profile, in the sense of starting with the final product of the process (the graduate's profile) and structuring training from there backwards, breaking with the logic of starting curriculum design with offer of content available in the institutions to reach the egress profile from there (CNI et al., 2020).

In this way, teaching strategies such as project pedagogy and the elaboration of learning outcomes replace the exclusive focus on the transmission of bookish knowledge. In a sense, the new NCGs are impregnated with pedagogical logics that emphasize the act of learning, and the development of students' abilities and skills. From this perspective, as part of the pedagogical process of the NCGs, there are detailed requirements to be made in the Course Pedagogical Project, which must include the competences to be developed, both general and specific, articulated to the activities of teaching-learning and those of a complementary nature. In the field of didactics and assessment, theory and practice and the context of application are associated, necessary for the development of skills, through active methods, centred on teamwork, focused on simulating real work situations, both in the classroom and in extension actions and in the various forms of industry-school integration.

Several activities that promote integration and interdisciplinarity are also proposed. To this end, NCG suggests carrying out scientific initiation work, academic competitions, interdisciplinary and transdisciplinary projects, extension projects, volunteer activities, technical visits, teamwork, prototype development, monitoring, participation in junior companies, incubators, and other entrepreneurial activities (BRAZIL, 2019b). According to the methodology, the curriculum can be built through the following steps (CNI et al., 2020):

- Determine a set of competences of the graduate (general and specific).
- Indicate specific skills.
- Structure the learning outcomes related to specific skills.
- Select the teaching contents so that the learning outcomes are achieved.

The NCGs prescribe a list of practical activities and learning spaces, which can be: presential, virtual, remote, itinerant (on mobile equipment) or collaborative (in partnerships with public and private institutions). Regarding assessment, the new NCGs emphasize some pedagogical principles and continuous assessment, which do not prioritize only the mention of a degree (formative assessment); the diversification of assessment instruments, which can be done through monographs, exercises or dissertation tests, presentation of seminars and oral practices, reports, projects and practical activities, among others, that demonstrate learning and stimulate the intellectual production of students, individually or in a team (CNI et al., 2020).

Finally, the NCGs describe content as factual, conceptual, procedural knowledge related to the cognitive capacities of remembering, understanding, and applying, in addition to more complex cognitive processes such as evaluating, analysing, and creating. Other recommended methodological indications are the following curriculum construction strategies (CNI et al., 2020):

- Correlate the general objectives of the course with the egress profile.
- Build a framework relating the overall objectives of the course with specific objectives of the tracks and curricular components.
- Divide each objective (competence) into its components (skills, knowledge, and attitudes).
- Build a framework relating different assessment instruments and the components with which they can assess, as well as the respective cognitive dimension.
- Relate each competence with the evaluation instruments used.

The Brazilian Army curriculum construction methodology

The Brazilian Army was based on the methodology of SENAI - National Industrial Learning Service (SENAI, 2009), inserting important customizations such as the Transverse Axis, containing skills, attitudes, and values inherent to the engineering profession. This Transverse Axis was obtained through a brainstorm carried out by professionals with different levels of professional experience related to their respective qualification area.

Some customizations are due to what already existed before the implementation of teaching by competencies in the Brazilian Army. For example, the psychological characteristics of graduates were described in the Professional Profile, a document that remained after the change in the educational paradigm, incorporating the mapping of competences, which is a document called the Functional Map, in addition to presenting a selection of components of the Transversal Axis.

That is, the Professional Profile still establishes the personality traits of the graduate, as was done before, but its indication is now based on an inference process centred on the description of the work activity, which appears in the Functional Map. From there come the elements of the so-called Transversal Axis, which permeate the entire curriculum, in the curricular, didactic and evaluation aspects. Next, the methodology of the Brazilian Army stipulates that the Integrated Plan of Disciplines (IPD) be completed, which explains what the contents are necessary to carry out an interdisciplinary activity. The Discipline Plan (DP) is also completed simultaneously with the IPD, as it is necessary to establish the disciplines at the same time as the intersections between them. The elements of the Transversal Axis are also included in the IPD and DP (BRASIL, 2022).

In this methodology, there are three types of disciplines:

- Disciplines directed to competences.
- Disciplines for the development of existing skills, attitudes and values in the Transversal Axis.
- Disciplines of fundamentation and instrumentalization, which establish the bases of disciplinary knowledge and provide the learning of useful technical knowledge in various disciplines and different work activities.

Finally, the Course Pedagogical Project is the document that consolidates the existing information in the Professional Profile, in the Integrated Plan of Disciplines and in the Discipline Plans. The General Table of School Activities is presented in the Course Pedagogical Project, which is a document that contains the distribution of the workload of subjects and integration activities. In addition, the Course Pedagogical Project shows constructive alignment (Biggs, 1996) as a way of evolving the undergraduate course, the characteristics of faculty training and the methodology for evaluating the program and possible improvements.

Regarding the pedagogical methodology of the Brazilian Army, priority is given to active teaching-learning methods, centred on the student, such as various types of academic group activities, project-based learning, and problem-solving methods. Several systematic planning and evaluation of the so-called learning contents are also proposed: factual, conceptual, procedural, and attitudinal, which are distinguished according to different teaching-learning processes, requiring different didactic and evaluation procedures (Coll, Pozo, Sarabia, & Valls, 2020). In turn, in the educational evaluation part, several instruments are foreseen. In addition, there are tools for checking results in assessments that are capable of scaling student performances, based on certain criteria (BRAZIL, 2020).

THE CHALLENGE OF METHODOLOGICAL INTEGRATION

The new NCGs indicate all the requirements that must be present in the Course Pedagogical Project to meet the needs of the engineer who graduated from a Brazilian university. In summary, the Course Pedagogical Project must clearly contain the learning outcomes, all academic activities to achieve these objectives, teacher training and appropriate assessment forms for each type of activity selected. Academic activities involve lectures, active learning, extracurricular activities, teamwork, and use of laboratories. This concept of constructive alignment, present in all approaches presented in this work, is shown in Figure 1.

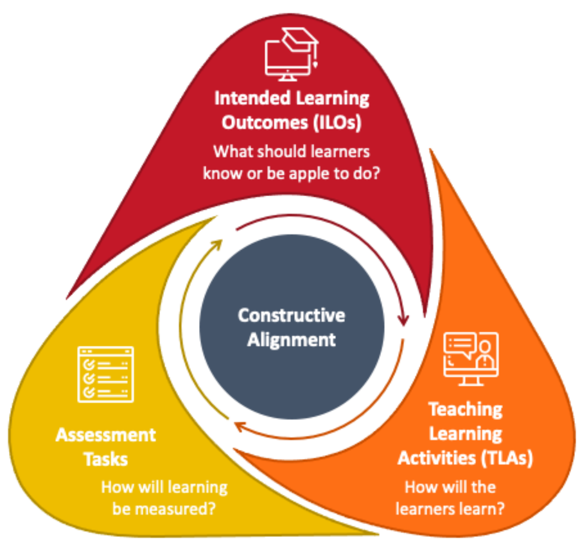

Figure 1: Constructive alignment (Biggs, 1996).

However, the NCGs do not show a methodology for curriculum construction. It should be noted that the Brazilian Ministry of Education conducts periodic evaluations of each undergraduate course to verify whether the respective Course Pedagogical Project complies with the NGCs. In case the Course Pedagogical Project does not comply with the NCGs, the undergraduate course may be disqualified to graduate new professionals.

The CDIO approach uses a curriculum construction methodology through the CDIO Standards. The content of the Course Pedagogical Project, determined by the NCGs, is very much in line with the topics to be developed by the CDIO Standards (Rezende, Neto, & Rodrigues, 2022).

The Brazilian Army curriculum construction methodology provides the documentation of the steps up to the final construction of the Course Pedagogical Project. In Brazil this is important because the Course Pedagogical Project is an evaluation document in according with the Brazilian education law. During the development of the Course Pedagogical Project, the documentation proposed by the Brazilian Army methodology was considered very useful, as it helped to consolidate the guidelines contained in the CDIO Standards, the needs prescribed by the new NCGs and the ideas of all participants in the curriculum construction process.

Table 1 shows the summary of the synergy between the existing curriculum construction topics in the new NCGs, in the CDIO Standards and in the methodology of the Brazilian Army.

Table 1. Alignment of the new NCGs propositions, CDIO Standards and documents in Brazilian Army methodology for the Course Pedagogical Projects.

Propositions for Course Pedagogical Project by NCGs	CDIO Standards	Brazilian Army methodology
Induction of innovative institutional policies	CDIO as context	Course Pedagogical Project
	Program evaluation	Course Pedagogical Project
Focus on teaching through skills development	Integrated curriculum	Integrated Plan of Disciplines
	Learning outcomes	Professional Profile Competences + Transverse Axis
Emphasis on managing the learning process	Introduction to engineering	Integrated Plan of Disciplines
	Integrated learning experiences	Integrated Plan of Disciplines
	Learning assessment	Discipline Plan
	Engineering workspaces	Discipline Plan
Relationship strengthening with different organizations	Design-implement experiences	Integrated Plan of Disciplines
Innovative teaching methodologies	Active learning	Discipline Plan
Valuing faculty training	Enhancement of faculty competence	Course Pedagogical Project
	Enhancement of faculty teaching competence	Course Pedagogical Project

Another topic for integrating the methodologies is the selection of knowledge, skills, and attitudes that engineering students should have when they leave university.

The participants began the curriculum design process through a careful study of the CDIO Syllabus, to compare it with the learning outcomes established by the Brazilian education laws, the engineering companies and society. For engineering higher education, the Brazilian law determines the learning outcomes are in accordance with the NCGs for engineering courses (Brazil, 2019b). To exercise the engineer profession, the Federal Council of Engineering and Agronomy (FCEA, 2005) establishes the activities, abilities, and responsibilities of the engineer. The knowledge, skills, and attitudes, determined by the National Curricular Guidelines of Engineering Undergraduate Programs (Brazil, 2019b) and by the Federal Council of Engineering and Agronomy (FCEA, 2005), present a strong similarity. In this way, Table 2 correlates the demands of National Guidelines and Federal Council of Engineering and Agronomy (FCEA, 2005) with the skills and knowledge proposed by the sections of the CDIO Syllabus.

Table 2. Correlation of competences between the Brazilian aspects and the CDIO Syllabus.

Competencies established by the NCGs and by FCEA		***CDIO Syllabus***
Apply mathematical, scientific, technological, and instrumental knowledge to the engineering	➡	*Disciplinary knowledge and reasoning*
Design and conduct experiments and interpret results	➡	*Personal and professional skills and attributes*
Planning, supervise, elaborate, and coordinate engineering projects and services		
Identify, formulate, and solve engineering problems		
Develop and/or use new tools and techniques		
Understand and apply professional ethics and responsibility		
Assume the posture of permanent search for professional updating		
Communicating effectively in written, oral and graphic forms	➡	*Interpersonal skills: teamwork and communication*
Work in multidisciplinary teams		
Conceive, design, and analyze systems, products, and processes	➡	*Conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context – the innovation process*
Supervise the operation and maintenance of systems		
Evaluate the impact of engineering activities in the social and environmental context		
Evaluate the economic feasibility of engineering projects		

Table 2 shows that the CDIO Syllabus addresses all the needs of Brazilian education laws and the exercise of engineering activity in companies (Federal Council of Engineering and Agronomy requirements). The Brazilian Army methodology involves military engineer skills with characteristics very similar to the CDIO Syllabus and will not be detailed in this paper.

Bearing in mind that the CDIO Syllabus is current research, which meets the needs of the modern engineer, the IME working group decided to adopt the CDIO Syllabus as a basis for choosing skills and attitudes, with the necessary customizations for each engineering program. Thus, as previously described, this knowledge, skills and attitudes will be present in the Professional Profile document.

FINAL REMARKS

The IME's curriculum construction methodology was built from the Brazilian Army methodology, the new NCGs and the CDIO approach, through customization procedures. The Brazilian Army's methodology was predominant due to its greater simplicity and because it was a curriculum construction methodology and not a diagnostic one, which was more important, allowing the quick execution of the teaching reform in ten engineering courses - a not insignificant factor in view of the pressing deadlines for the implementation of the new guidelines for engineering education, required by the Brazilian Ministry of Education, as well as for competence-based learning, demanded by the Brazilian Army.

Another relevant innovation in the face of the Army's methodology was the insertion of skills, which were included in the CDIO and in the new NCGs, and were incorporated in the Transversal Axis, to appear in Integrated Plan of Disciplines and Discipline Plan, with clear indications for their development in didactic situations and of evaluation.

It is important to highlight that, despite the IME methodology being based on curriculum construction, it is based on the analysis of existing curricula, which are subjected to criticism in the context of engineering programs and to a process of transposition to new models of documents to the new education curriculum. Numerous pedagogical training sessions were carried out for program coordinators to prevent the reform from merely changing terminologies, maintaining the same customary logic of content selection, based above all on school traditions. It is important to emphasize the fact that for more than 5 years the ideas of the CDIO and the methodology of the Brazilian Army have been disseminated through lectures and small training sessions for professors, facilitating the acceptance of IME faculty. The acceptance of active learning and interdisciplinary approaches is considerable, being marked by some spontaneous experiences of professors in different programs.

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EMBEDDING SUSTAINABILITY AND ETHICAL COMPETENCES INTO ENGINEERING EDUCATION FOLLOWING CDIO

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ABSTRACT

Integrating sustainable development and ethics into engineering education is essential for every higher education institution. The CDIO syllabus contains both principles, and CDIO 3.0's optional standards promote the integration of CDIO principles into the curriculum of educational institutions. In this context, <Institution> conducted research to determine the level of familiarity engineering students have with ethics and sustainability and to gather their suggestions on how to incorporate these principles into the curriculum. An anonymous web survey was administered to students in three different engineering fields, including ICT (N = 58), Land Surveying (N = 12), and Civil Engineering (N = 32). The survey evaluated their understanding of sustainability and ethics and sought their opinions on how these topics were addressed in their coursework. The content analysis also revealed the perspectives of the students, which suggested practical examples, learning tasks, and the occurrence of themes cross-cuttingly, e.g., in learning projects. The results reflect the thoughts and ideas of stakeholders and give suggestions for practical implementation to incorporate themes into learning. The inclusion of these themes in the practical implementation of the study courses contributes to the integration of ethics and sustainable development into the curricula following the CDIO 3.0 principle and improves the quality of the curricula for its part. The results of a study investigating engineering students' knowledge of sustainability and ethics, as well as their suggestions for incorporating these themes into the curriculum, can be of benefit to the CDIO community. The study found that students generally understand the principles of these themes, but also suggested practical examples and cross-cutting themes for more effective integration into the curriculum. The findings can inform the development of new teaching methods and learning materials, as well as improvements to current CDIO standards, to better integrate sustainability and ethics into engineering education. Ultimately, this can lead to a more relevant and engaging learning experience for students, promoting their commitment to becoming socially responsible engineers.

KEYWORDS

Sustainability, ethics, curriculum, continuous improvement, Optional standards: 3.0 nr 1

INTRODUCTION

As engineers design and develop new products and technologies, they need to consider the impact of their work on society, the economy, and the environment to ensure sustainable solutions. This requires collaboration with stakeholders and interdisciplinary thinking to balance technical and non-technical factors.

Sustainable development means development that ensures good living conditions for present and future generations. The 2030 Agenda for Sustainable Development Goals (SDG) by UNESCO (2017a, 2017b) aims to eradicate extreme poverty and achieve sustainable development that takes equal account of the environment, the economy, and the people. Its guiding principle is that no one should be left behind in development.

Svanström et al. (2008) have found in the literature about the learning outcomes of sustainable development, common features independent of educational level and target group, such as systemic and comprehensive thinking, integration of different perspectives, emphasized skills, and the appearance of attitudes and values in the learning outcomes. Leiva-Brondo et al. (2022) emphasise the importance of finding connections between daily interests and SDGs in the planning of education strategies. Sustainable development perspectives have been successfully integrated, e.g., into modules (see e.g., Butt et al., 2022) and courses (see e.g., Gunnarsson & Klein, 2021). Indeed, the literature includes an increasing number of studies on sustainability and the integration of sustainable development into engineering curricula (Thürer et al., 2018). There are plenty of studies in the literature on what and how to teach and engage students in the development of sustainable development knowledge and skills through innovative teaching methods and innovations (Desha et al., 2019). According to the literature review by Thürer et al. (2018), SDG was incorporated into curricula for example by adding new courses, adapting existing ones, or introducing the topic through project work.

Along with sustainable development perspectives, ethical issues are also an integral part of engineers' personal and professional lives, connecting micro-ethical problems with macro-ethical consequences (Rottman & Reeve, 2020). In ethics education, in addition to the massive ethical questions, it would be good for engineering students to think about how they relate to daily problems, colleagues, customers, and stakeholders in their community (Pierrakos et al., 2019). Students have been found to experience non-technical perspectives on ethics also uninteresting (Ermer & VanderLeest, 2002), which is why their involvement in designing their learning is important.

In Finnish Universities of Applied Sciences, the competences of qualifications are defined as education-specific and common competences by the rectors' conference of Finnish Universities of Applied Sciences (Arene, 2022). Competences are defined as broad sets of competences, combinations of an individual's knowledge, skills, and attitudes. The programme-specific competences form the basis of a student's professional competence. Competencies shared by various qualifications and diplomas form the foundation for professional endeavours, collaboration, and expertise advancement. The recommendation on the application of common competences in higher education degrees is to promote an understanding of how to apply the competences described in the National Qualifications Framework (NQF) to curriculum development, competence profiling, and assessment. The Finnish qualifications framework is based on the recommendation of the European Parliament and of the Council on the establishment of the European Qualifications Framework (EQF) for lifelong learning. The Finnish qualifications framework is also in line with the European Higher Education Area (EHEA) qualifications framework.

The aim of this development project is to assess the current knowledge of sustainability and ethics among students at our university and use the results to develop new teaching and curriculum that better incorporate these topics. Additionally, this study aims to share the findings with the CDIO community to inform sustainability and ethics education in other universities. Further, to ensure continuous improvement of the engineering education curriculum, it was asked, what are students' expectations for developing sustainability and ethical considerations in engineering education curriculum and pedagogy? The survey and the results are presented in the following chapters

DATA COLLECTION AND ANALYSIS METHODS

To provide background information on the embedding of ethical and SDG competencies into learning, collecting thoughts from engineering students as an anonymous web survey is considered the most appropriate in this study. The survey was sent to all engineering students (ICT engineering N= 315., Civil Engineering (CE) N = 426, Land Surveying engineering (LS) N = 279) at the Rovaniemi campus of the Lapland University of Applied Sciences at the beginning of October 2022, and two weeks were given to answer.

The web survey was conducted with the Webropol v. 3.0 system in Finnish. At the beginning of the web survey, the students were told e.g., the purpose, voluntary nature, the policies for publishing the results, and the principles of data storage. After the demographic information, the students were asked to assess whether they know the meaning of the term's sustainability and ethics and ethical principles. There were two questions regarding sustainable development. They were preceded by the CDIO (2022) consortium's rationale for sustainable development and the goal of integrating them into engineering education. In the first question about sustainable development, students were asked to evaluate the current stage in education in terms of incorporating sustainable development perspectives into teaching and learning. The question was identical to the optional standard 1 for sustainable development (Malmqvist et al., 2020) in CDIO's (2022) optional standards 3.0 and provided statements to determine the level following the rubric for self-assessment. The optional standard is useful, not only for assessing the integration of sustainable development but also for promoting and guiding it (Rosén et al., 2021). The second question was open-ended, asking for suggestions and expectations regarding the organization of sustainable development learning tasks. Furthermore, there were three questions regarding ethics. As an initial introduction, the Archimedean oath was presented to the students, and research ethics and professional ethics of engineers were defined according to Heikkerö (2009). The first question regarding ethics inquired if the student was aware of what is meant by the term responsibility. Examples such as reference management, copyright, rights of participants in research, GDPR, and critical media literacy) were given. The second question investigated students' awareness of the meaning of respect. Again, some examples were given to guide thinking, such as respect for colleagues, research partners, and fellow students. Finally, the open question asked for suggestions and expectations for introducing ethical perspectives in education.

The answers to the survey were as follows: engineering students of ICT (N = 58), Land Surveying (N = 12), and Civil Engineering (N = 32). Overall, 102 responses were received, giving a modest response rate of 10 % (ICT 18%, CE 8 %, LS 4 %). Of the students who responded, 40 studied in the daytime group and 58 in multi-format or online studies, and two students studied in some other. Most of the respondents represented early-stage students. Of the respondents, 33 (32.4 %) were first-year students, 34 (33.3 %) were second-year, 16 (15.7%) were third-year, and 19 (18.6%) were fourth-year students or more.

In the content analysis (Bengtsson, 2016; Elo et al., 2014) of the open answers, the answers were first read through and divided into analysis units, which were labelled as codes. Answers that were not related to the topic were excluded. The codes were classified into categories/themes using inductive reasoning (Bengtsson, 2016). The authors went through the thematic categories together to form a consensus.

RESULTS

Most of the students, 95 (93 %), claimed to have knowledge of the meaning of sustainable development. There were 6 (6 %) who did not know and 1 (1 %) were blank answers. There was a minor difference between the degree programmes. Regarding the concept of ethics, 83 (81 %) of the respondents knew the meaning of the concept, 18 (18 %) did not know and 1 (1 %) was blank. Among ICT students were the highest proportion of NO answers 11 (19 %). Compared to Land Surveying (LS), the corresponding value was 2 (17 %), and Civil Engineering (CE) 5 (16%).

Students evaluate the inclusion of sustainable development perspectives in their education program in their learning according to Figure 1. The statements by the CDIO standard were cited from the CDIO (2022) rubric for self-assessment in the first Optional standard 3.0.

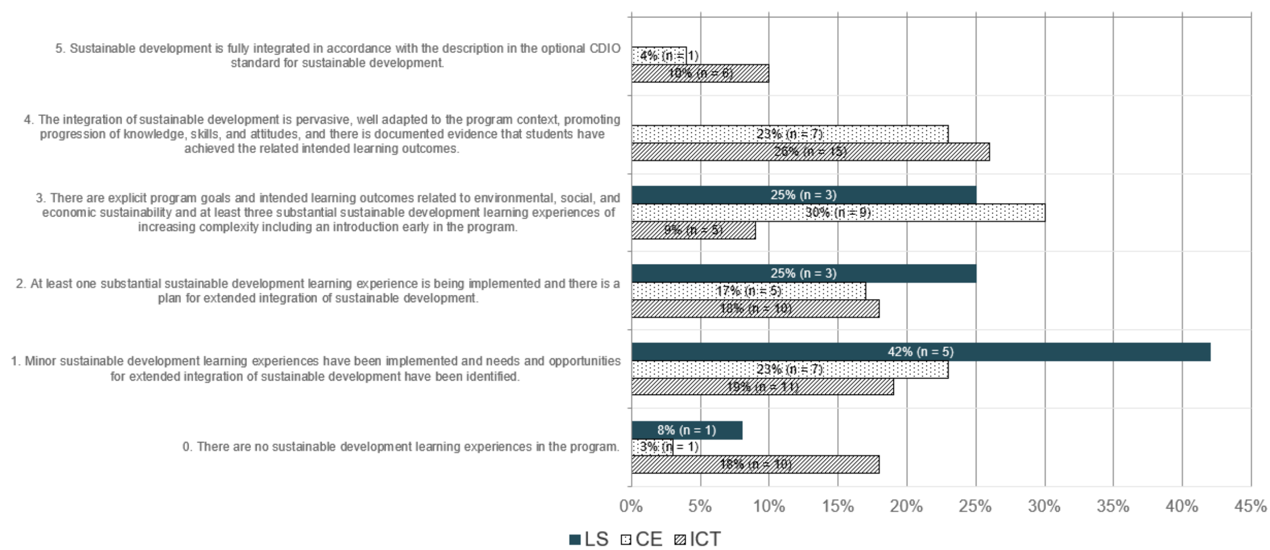

Figure 1. Students' assessments for the sustainable development statements by degree programmes.

Most of the engineering students answered that their education is either at level 1 (N = 23, 23%) or level 4 (N = 22, 22%) in the rubric. Level 5 received the fewest responses (N = 7, or 7%). Between the degree programmes (see Table 1) it appeared that all answers of LS were at levels 3, 2, 1, and 0, at levels 4 and 5 there were no answers. Regarding CE and ICT, all levels received answers. The fewest answers (N = 7.7%) were graded 5, i.e., sustainability is comprehensively integrated into the degree programme according to the description of sustainable development in CDIO optional standard. The pairwice Mann-Whitney U-test show no evidence against the null across degree programmes (LS vs. CE: U = 221, p = 0.0566; CE vs. ICT: U = 736.5, p = 0.4785, LS Vs. ICT: U = 360, p = 0.3743).

Table 1. Students' assessments for the level according to the rubric of sustainable development statements in CDIO optional standard by degree programmes.

	ICT		LS		CE		
Level	N	%	N	%	N	%	Total
5	6	10,5 %		0,0 %	1	3,4 %	7
4	15	26,3 %		0,0 %	7	23,3 %	22
3	5	8,8 %	3	25,0 %	9	30,0 %	17
2	10	17,6 %	3	25,0 %	5	16,7 %	18
1	11	19,3 %	5	41,7 %	7	23,3 %	23
0	10	17,5 %	1	8,3 %	1	3,3 %	12
Total	57		12		30		99

The LS degree programme had relatively the most level 2 responses (N = 5, 42 %), i.e., small-scale implementations of sustainable development. Corresponding values were for CE (N = 7, 23%) and ICT (N=11, 19 %). Almost one-third of ICT engineering students estimate that the degree programme is at level 4 (N = 15, 26 %) or 5 (N = 6, 10 %). CE has the most answers at level 3 (N = 9, 30 %). Levels 4 and 1 had the same number of answers (N = 7, 23 %).

The concept of responsibility was familiar to the students. There was a total of 93 positive answers (92%). The corresponding response numbers between degree programmes were LS (N=11, 91.7%), ICT (N = 51, 89.5 %), and CE (N = 28, 96.6 %). There was one missing answer. The concept of respect was also generally well-known. Most of the students (N = 100, 98.0 %) knew the importance of respect in operations. There were not many differences between the degree programmes. There were two negative answers from ICT engineering students.

Table 2. lists students' suggestions for including sustainable development in learning by theme. A total of 47 responses were received: 5 from LS, 13 from CE, and 29 from ICT. Learning projects were most wanted in six comments, but they only appeared in ICT students' answers. I don't know –answers were 1 in LS students' answers, and 2 in CE and ICT students' answers.

Table 2. Students' suggestions for including sustainability in learning.

LS	CE	ICT
Practical examples	Recycling and reuse of building materials (3 answers)	Learning projects (6 answers)
Opportunities for utilization in the future	Construction-related learning projects (2 answers)	Reflection and learning assignments (4 answers)
Basics of sustainable development	Review of general goals and problems	Energy conservation and renewable energy (3 answers)
Learning assignments	Comparison of different building materials and their durability	Practical guidance through the curriculum (3 answers)
	Possible ways to improve the materials	Info/event/presentation (2 answers)
	Economic factors	Technology's support for nature (2 answers)
	Should be in everything	Home energy efficiency (2 answers)
	Wood construction on a large scale	Optimization of algorithms from the point of view of energy consumption
	Opportunities offered by own electricity production	Perspectives related to citizens' well-being and health care
	Quality of Construction	Calculation of life cycle costs and investments
		Life cycle thinking of applications and systems
		Practical examples
		Electrical and home automation

There were concrete answers related to the theme of sustainable development, for example, the following response from the CE student:

> *In connection with construction, a project where, for example, sustainable development is supported e.g., with own electricity production (wind power).* (Translated from Finnish)

Table 3 describes the students' suggestions by themes for including ethical perspectives in learning. A total of 44 responses were received, of which 5 were from LS, 9 from CE, and the remaining 30 from ICT. The students suggested that the theme should be cross-cutting, which at Lapland UAS means including the theme holistically in the curriculum during the entire study path from the point of view of each subject. There was a total of 6 responses related to this theme.

Table 3. Students' suggestions for including the ethical themes in learning.

LS	CE	ICT
Principles of research and professional ethics (2 answers)	Conflict resolution (2 answers)	Cross-cutting (5 answers)
Learning projects	Separate ethics course (2 answers)	Principles of research and professional ethics (4 answers)
Copyrights	Reflection assignments (2 answers)	Copyright, GDPR (2 answers)
Review in connection with Thesis	Privacy (2 answers)	Separate ethics course (2 answers)
In connection with orientation studies (organized for the first-year students)	Interaction and communication management	Practical examples (2 answers)
	Information security	Learning projects (2 answers)
	Value discussion	Ethics of application and system development
	Instructor's examples	Equality issues
	Ethical use of natural resources	Source criticality
	Cross-cutting	Information packages
	Emphasizing quality	

Furthermore, research and professional ethics were mentioned in 6 responses and separate ethics courses were suggested in 4 responses. There were 7 total responses suggesting research and professional ethics be included in learning, but they were not further specified. For example, the student from the ICT degree programme suggested a deeper discussion of source criticality:

> *At least I haven't come across GDPR in my studies, but I've delved into it in my work. We could always talk more about source criticism.* (Translated from Finnish)

Data protection and copyright came up in the answers of students from each degree programme. Two CE and one ICT student answered that they do not know.

DISCUSSION

According to the survey results, it can be concluded that the students believe they have a good understanding of both sustainable development and ethics. They were able to assess the extent to which these principles are incorporated and emphasized in their educational programs, based on their perception.

The level of sustainable development education was evaluated on a 6-point scale from 0 to 5, where 0 and 5 represent the extremes. Based on the distribution of the answers, the students' opinions were spread over the entire scale. For example, levels four and one had almost the same number of answers in both. 46 answers were rated better than level three and 53 answers were given a level two or lower. In the comparison between sectors, LS gave the most negative evaluations and ICT the most positive.

As shown in earlier studies, the project-based learning curriculum has shown its effectiveness. ICT-Department projects are real-life projects either from local companies or R&D projects with other stakeholders. The suitable courses are integrated into the project and learning is done according to the same rules as in working life in real companies and projects (see e.g., Angelva et al., 2017). Learning projects emerged in the results of this study as well, when students suggested incorporating SDG perspectives and ethical issues into them. According to Guerra (2017), education for sustainable development is one of the challenges engineering education currently faces. In engineering education at Aalborg University, problem-based learning is an answer to integrating sustainability in engineering curricula by sharing core learning principles and by enhancing competencies for sustainable development and professional expertise. The study made by Guerra (2017) shows that it is necessary to look further into curriculum elements: knowledge and learning objectives, types of problems, resources, staff and students' roles, and assessment. Alaswad & Junaid (2022) provided successful examples of integrating discussions into sustainable development themes in engineering education. In the case of ethical issues, the students in this current study also suggested cross-cutting. Indeed, this could also be implemented through problem-based or project-based learning in authentic industry-based project assignments. From the students' answers to open questions, some suggestions can be included in practical teaching and learning. For example, civil engineering projects may contain requirements for emission-free energy production and energy consumption in buildings. Furthermore, life cycle costs and investment calculation as well as traditional aspects of recycling, e.g., on construction sites, can be included in the learning contents of the projects.

The engineering students at Lapland UAS possess a thorough understanding of the goals of sustainable development, according to their perception. This contrasts with the results of a study conducted by Leiva-Brondo et al. (2022) among Spanish university students, where only 15.9% considered themselves to have a strong knowledge of these goals. This difference may be attributed to a variety of factors, such as prior academic background or age distribution. It should be noted that Finnish university students, including a substantial number of adult learners, tend to start their studies at a later age compared to many European countries. However, no information was gathered in the present study on the sources of the student's knowledge or their ages.

To integrate ethics into learning, responses from students in this study included several suggestions for separate ethics courses in engineering and research ethics as well as practical examples. Rottman and Reeve (2020) encourage practitioners to create open-ended case studies depicting the ethical dilemmas experienced by various engineering groups, and prompt students to identify the macroethical consequences of microethical dilemmas in these cases. Case studies are one of the most popular ways to integrate ethics (Hess & Fore, 2018) and found to be successful in several studies (see e.g., Loendorf, 2009; Martin et al., 2021).

There are some concerns with this study that the reader should consider. First, the response rate was modest, and the small sample size can cause distortion of the results and does not represent the opinions of the entire population. Secondly, students cannot know if the degree programs have plans to include the SDGs in the curriculum (see level 2 rubric). Thirdly, the descriptions of the rubric's levels have been translated from English to Finnish, so the tone and nuances of the descriptions may have changed or been distorted. Furthermore, it is unclear whether the students' answers would have changed if they had studied and understood the themes more deeply. Despite these limitations, the authors believe that the research results achieved a sufficiently reliable answer to the research question for further measures.

The survey data can be used when developing the contents of teaching and study plans in such a way that ethical questions and the principles of sustainable development are considered in teaching. The results of the survey can also be used when comparing the results of other higher education institutions with each other, provided that the survey is carried out using a sufficiently similar method. The answers to the open questions can be used directly in the implementation of teaching and the development of curricula. Naturally, the layout of the questions and the survey method can be further developed and improved in the future.

CONCLUSIONS

The study found that students have a basic understanding of both themes, but also suggested practical examples, cross-cutting themes, and learning tasks to effectively integrate ethics and sustainable development into the curriculum. The findings can inform the development of new teaching methods, learning materials, and improvements to current CDIO standards to better integrate ethics and sustainable development into engineering education.

The study shows the importance of benchmarking the results of different higher education institutions and developing new teaching methods and learning materials to better integrate ethics and sustainable development into engineering education. Ultimately, the inclusion of these themes in the practical implementation of study courses can lead to a more relevant and engaging learning experience for students, promoting their commitment to becoming socially responsible engineers.

Further research is needed e.g., to find out the effectiveness of any measures taken and student satisfaction. It could also be interesting to map how students reflect on their own competence after studying SDG and ethics themes.

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DEVELOPMENT OF SIMULATION TOOLS TO ENHANCE THE REAL-WORLD CONNECTIONS FOR ACTIVE LEARNER

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ABSTRACT

A new utility of computer graphics (CG)-based simulation in the class is discussed in connection with the Active Learning through the activity in the physics class of National Institute of Technology, Tsuruoka college. It is proposed to utilize the simulation to connect the learner's schema in daily life with the system learned in physics class. Especially, it is aimed to effectively introduce the concept of idealization in the fundamental physics for learners. This topic is closely related with how to motivate the learner toward the active and independent learning beyond the memorization-based learning like pattern matching.

KEYWORDS

CG simulation, Conceptional understanding, Real-world connection, Standards: 8, 10,11

INTRODUCTION

How to effectively utilize ICT tools, in connection with the Active Learning (AL) (Standard 8) and related teaching competence (Standard 10) with learning assessment (Standard 11), is one of important and hot topics in modern engineering education. From the teacher's side, these tools are expected to give a variation for the learning, enhancing the independence of learners (Khoon, Leong, Joo & Anwar, 2021), (Onufrey, Berglund, Bienkowska, Magnusson & Norrman, 2019). Related to this topic, computer graphics (CG)-based simulation tools, including virtual/augmented/mixed reality technology are now widely introduced in the classes to support the learner's understandings (Hatchard, Amin, Rihawi, Alsebae & Azmat, 2019), (Yang & Cheah, 2020), (Yu & Li, 2020).

One of existing problems in engineering education, especially in the study of theory, is that learners are often missing a link among theoretical contents and the real situation, which may be experienced in the laboratory activities or in the real life. In this case, the learning may become just a pattern matching or memorization to gain the score for the credit, resulting in a passive attitude in the class. Furthermore, in such a situation, the motivation for the learning may be lost. Physics is one of subjects that such a situation is frequently seen. In the Physics Education Research (PER), a lot of effective teaching methods have been developed with the assistance of the cognitive science to overcome the above problem (Redish, 2003), (Wieman, 2007). While the interactive and learner-oriented teaching methods have been developed, the use of the CG-based simulation tools is one of new stream in the PER (Wieman & Perkins, 2006), (Granholm & Ohnishi, 2018), (Suzuki, Kazi, Wei, DiVerdi, Li & Leithinger, 2020).

In this paper, we will argue about what kinds of essences or tricks are necessary to realize an active learning environment with CG-based simulation tools, focusing on the introductory physics for the engineering from the activity in National Institute of Technology, Tsuruoka college (NITTC). In the AL, what the student does is actually more important in determining what is learned than what the teacher does, as suggested in (Shuell, 1986) (Murphy & Kontio, 2018). On this point, our insight discussed below is brough through the interactive communication with the students by interview, and hence, our study would be useful in many classes, although we discuss about our experience in physics class.

OUR ACTIVITY

National Institute of Technology (NIT) called KOSEN in Japan has a hybrid educational system of high school and college with the five year's curriculum, which are extended with the two year's advanced course for a bachelor's degree. In Japan, there are more than fifty NIT colleges, and all the NIT colleges commonly have fundamental physics classes as a basis for the engineering.

In NITTC, the physics class starts from the second grade with algebra-based contents (which are standard high school level in Japan), and are continued up to 4th grade, migrating to the calculus-based contents of the introductory university level. Each class consists of lectures, laboratory works, team discussions and e-learning by using LMS. To evaluate the conceptional understandings of the learners, the survey by using the Force Concept Inventory (FCI) has been introduced. It should be noticed that this survey is not for the assessment of the course, but for the feedback to prove our class overall to determine whether the instruction we are delivering is meeting our goals. The FCI is one of major surveys to measure the conceptional understandings about mechanics (Hestenes, 1992), (Redish, 2003). The FCI consists of thirty questions with multiple-choice format and the question 1 is shown in Fig.1 as an example. While we conduct the FCI, we also have another survey which are introduced as a review exercise in the class. This review exercise asks practically the same thing with the FCI questions but with the format answering numerical values or algebraic format as shown in Fig.1. We have analyzed these two surveys to evaluate the gap between the conceptional understandings and problem-solving techniques.

FCI Q1
Two metal balls are the same size but one weighs twice as much as the other. The balls are dropped from the roof of a single story building at the same instant of time. The time it takes the balls to reach the ground below will be:

A) about half as long for the heavier ball as for the lighter one.
B) about half as long for the lighter ball as for the heavier one.
C) about the same for both balls.
D) considerably less for the heavier ball, but not necessarily half as long.
E) considerably less for the lighter ball, but not necessarily half as long.

Review Exercise: An Example
Objects A and B have masses m [kg] and $2m$ [kg], respectively. They are dropped from rest simultaneously. Find the magnitudes of acceleration for both objects, where magnitude of gravitational acceleration is given by g [m/s^2].

Answer:
EOM for A : $ma_A = mg \quad \therefore a_A = g$
EOM for B : $2ma_B = 2mg \quad \therefore a_B = g$

Figure 1. Question 1 in the FCI and the corresponding review exercise.

In this paper, we show the survey conducted in 2017-2019 for the class, consisting of 37 students belonging to electric and electronic engineering course of NITTC. The result is shown in Table 1. We can see a gain of total correct answering rate in the FCI year by year. Then, our instruction goes well in one sight. Total tendency of the present FCI result is nothing special compared with previous studies (Ohnishi, 2022). On the other hand, the highest correct answering rate for FCI Q1 is seen at second grade. This may be because the students learn about freely falling bodies at the second grade, and hence, many students remember the fact that is studied in class. When we look at the result of the review exercise related to FCI Q1, interestingly (from the viewpoint of teacher in charge, this is not interesting actually), the correct answering rate rises year by year. This result suggests that a certain number of students acquire the problem-solving skills year by year, but there is no gain in the conceptional understanding to the phenomenon, resulting in memorization-based learning.

Table 1. The correct answering rate for the question 1 of the FCI and the corresponding review exercise.

	2nd grade	3rd grade	4th grade
FCI Q1	84%	62%	68%
Review Exercise	73%	78%	84%
FCI (total)	35%	44%	46%

To investigate what happens more deeply, we had interview for students, who gave the incorrect answer for FCI Q1 and the correct answer for the corresponding review exercise. Some comments from the students are as follows:

- I know that the magnitude of acceleration for freely falling bodies does not depend on the mass of object, but I cannot image them. (Since you (the teacher) suggested that this survey is not related to the assessment of the class, I answered honestly along my sense.)
- It is a different activity to answer the questions along my sense with solving numerical or algebraic problems.
- There is no description that air resistance can be negligible in this problem.

These comments apparently indicate an isolation of their physical model or schema learned in class with the real world. Even if they know the correct answer, it is not connected with their schema constructed in daily life. An important thing is that this isolation is no matter for their daily life in many cases. What kind of trick or method is effective to improve this situation? In the AL environment, a learner is expected to have independent work with the own responsibility instead of teacher's guidance (Kontio, 2015). Then, it is important to show the appropriate direction for the learning in the beginning with giving the attractive motivation.

LINKING THEORY WITH THE REAL-WORLD

Important awareness in our survey is that there is a huge jump, which may bring a confusion for learners, in the beginning of learning in physics. In the conventional way, the learning starts from an idealized system with mass point system. In the motion of freely falling bodies, air resistance is neglected. These situations are quite different from our daily experience. In our life, every object has a size and shape and may deform. Motion of object such as translation and rotation apparently seems to be affected by friction and air resistance. Thus, learning of physics for beginners starts from unknown world. Afterword, extra factors such as air resistance, size of object are introduced, and the treating world is getting closer to the real world with the increase of mathematical difficulty, as shown in Fig. 2. In this flow, the teacher implicitly expects that the learner finally combines its schema for physics with the real-life experience, however, not a few learners cannot achieve them.

To overcome these difficulties, we propose a new way of learning by using the CG-simulation for an appropriate starting point of learning. Since the CG simulation can reproduce the variety of situation by changing the parameters, we can visualize both the realistic situation and the idealized one, and continuously connects both situations. As shown in Fig. 2, then, we can transfer from the realistic situation, in which the learner has a feeling for the phenomenon, to the idealized situation, by seeing how the system is affected by each physical parameter. In other words, the CG-simulation can utilize as an assistant of "thought experiment". The learner can think about what the idealization is and can understand the connection with the real world. This is a new possibility of the CG simulation, while we utilize the simulation to visualize the situation teacher wants to explain in many cases.

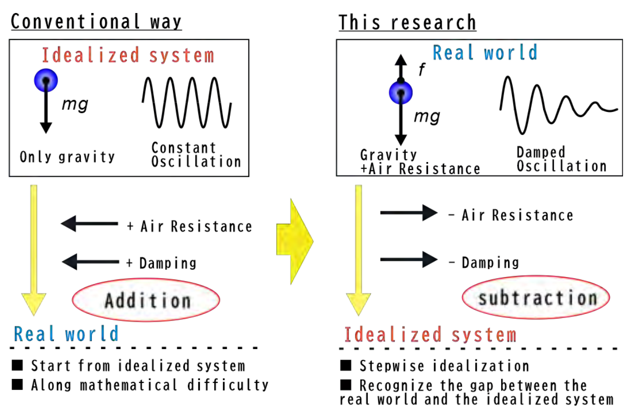

Figure 2. Direction of learning in conventional learning way (left) and the way proposed in this research (right).

The CG simulations to connect the real world and idealized system have been developed by using HTML5, and some of them have already been published in our site [Ohnishi, 2021]. An example of the developed simulation is shown in Figure 3. In this example, motion of two object on a slope can be compared, changing the strength of friction, mass, size, shape of objects, and so on. Hence, the learner can think about variety of situations, changing the parameters. In actual introduction of CG tools in class, we have interactive discussion among learners and with teacher, referring the Interactive Lecture Demonstrations method (Sokoloff & Thornton, 2001).

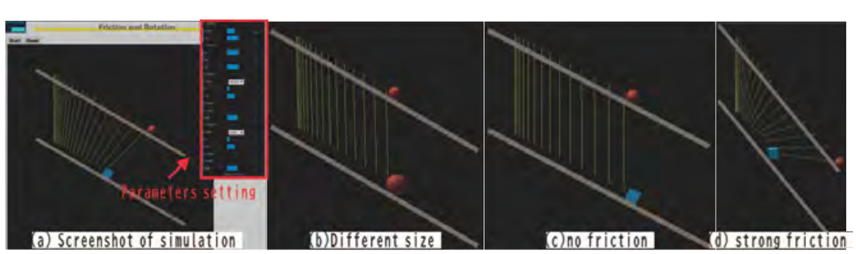

Figure 3. Screenshot of simulation for the motion of object on the slope.

As an example, the simulation given in Figure 3 is used to consider about how do size and shape of object affect to the motion on the slope. This topic is aimed to consider the idea of mass point, which does not have size and does not rotate. A typical flow of discussion is as follows: At first, the teacher indicates some situations, and the learners guess the result and its reasoning. Interestingly, even if the learners can guess the result correctly, its reasoning is incorrect in many cases. In the present case, many students think that the strength of friction depends on the contact area between the object and ground. In the second stage, we have a discussion among learners to compare the opinions. In the third stage, teacher show the case, which conflicts with learners' idea. If it is possible, the real demo is performed in this stage. After that, students consider whether they need to improve their schema or not. In our experience, it is better to change the implementation date until the second stage with third stage because the teacher can consider what should be proposed in the third stage carefully, basing on the learners' opinions. For the beginner, it is practically impossible to understand the idea of physics perfectly in this stage, but the learners can make an overlap between the real world and the idealized system in their schema. Furthermore, since the simulations are available on the web, it is always available in their independent work.

It should be noted that experiments at laboratory (or demo) is very important to improve or stimulate learners' schema since physics is an empirical science. However, experiments are not always easy to understand their meaning when they are technical and have errors, while such technical aspects with errors are inevitable in science. Furthermore, the time for experiments is limited in class. Hence, to motivate the beginner, experiments is not always the best option to learn the phenomenon. Video teaching materials, which record the phenomenon, is another option for learning. While they can use repeatedly, the situation is not able to change by users.

Since we do not have enough sets of simulations and coupled learning materials to argue the change of FCI score on the present stage, it is difficult to evaluate the effectiveness of the present method. However, we can see the rise of score in the survey about the real-world connection in preliminary. The questions are selected from the CLASS survey (Adams, et al., 2006). The questions consist of the following 4 questions.

A) Learning physics changes my ideas about how the world works.
B) Reasoning skills used to understand physics can be helpful to me in my everyday life.
C) The subject of physics has little relation to what I experience in the real world.
D) To understand physics, I sometimes think about my personal experiences and relate them to the topic being analyzed.

The Pre-survey and Post-survey were conducted in 2022 at NITTC for 81 students of second grade in the learning of motion of object on slope. The answer is given in a value from 1 to 5 (1 for strongly disagree and 5 for strongly agree) for each question. It should be noted that the lower score is preferred only in the question C. The result is given in Table 2. Except the question B, we can see the positive shift in the average score. The decrease of score in question B may be because the beginners have less confidence about their opinions, especially they start to understand the difficulty of physics in the learning progress. Although we need longer term observation with developing learning materials, we have gotten positive feedback for our proposal on the present stage.

Table 2. The average score about the real-world connection given in the text.

	A	B	C	D
Pre-survey	3.56	3.55	2.18	3.06
Post-survey	3.88	3.32	1.82	3.55

SUMMARY

We proposed a new usage of CG-simulations in the class. While the CG simulations are often used to explain what the teacher want to explain, they can be used to connect learner's concept or schema in the daily life with the system learned in physics class. Such CG simulations are expected to enhance the motivation for the learning along the appropriate direction. The key awareness for the present study, which cannot be seen in the survey by paper, is brought through the interview to the students. On this point, an interactive communication among teacher and students is one of crucial aspects for the improvement of class. The development of the CG simulations with coupled learning materials are still in progress. We will introduce about them elsewhere.

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THE KTH GUIDE TO SCIENTIFIC WRITING: SPARKING A CONVERSATION ABOUT WRITING

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ABSTRACT

The *KTH Guide to scientific writing* was created with the aim of supporting students and faculty with scientific writing in English. The guide is rooted in the typical writing genres of a technical university, and draws on examples of these to explore sentence structure, punctuation, text flow, and scientific style. Since its launch, the guide has become an integral part of classroom practice in the department of Language and Communication, and an online resource for all students and faculty at KTH. This paper presents our findings from the first stage of our evaluation of the guide. The evaluation consists of a short reflective questionnaire for users. We have begun to collect responses to the questions, and to conduct an inductive thematic analysis (ITA) to identify emerging themes.

KEY WORDS

scientific writing, academic writing, English language, communication skills, interpersonal skills, CDIO Standards 2, 9

INTRODUCTION

Internationalisation is now “deeply embedded in the structure and strategies” of Higher Education Institutions (HEIs) (Bond, 2021: 3), and this is reflected in the growth of English as a medium of instruction (EMI). In Sweden, a study of five Swedish HEIs (Malmström and Pecorari, 2022) found that two-thirds of the teaching on Master’s degrees is conducted in English, and that even on courses where Swedish is the official language of instruction, approximately half the required reading comprises texts written in English. English is even more prominent in doctoral studies in Sweden, where 93% of theses and research articles are written in English. The prevalence of English in Swedish HEIs is strongest in STEM, which has the highest proportion of international students, researchers, and teaching staff.

These statistics throw the question of language use into sharp relief, particularly in universities which identify as bilingual or multilingual. Language is central to effective knowledge communication, and thus central to the functioning of the university itself. The importance of engineering communication is reflected in the CDIO standards’ focus on interpersonal skills, including “communication, and communication in foreign languages” (CDIO Standard 2: Learning Outcomes), and Bond makes a compelling case for a more integrated approach to language across HEIs in her book *Making Language Visible in the University: English for Academic Purposes and Internationalisation* (2021).

One strategy for achieving greater visibility and discussion of language in HEIs is the creation of official university language policies that attempt to articulate and enhance the role of language in university practice. At our university, *KTH Royal Institute of Technology*, a language policy has been in place since 2010. *The KTH Language Policy* outlines the parallel status of Swedish and English, alongside a wider commitment to plurilingualism. It also encourages "clear language" and "high-quality communication", but does not go on to define exactly what is meant by these terms.

The KTH Guide to scientific writing was created to help students to understand what constitutes clear language and effective communication in English scientific writing, and to develop sound writing strategies. The guide is also intended to support faculty life-long learning, as reflected in the CDIO Standards (CDIO Standard 9: Enhancement of Faculty Competence) and KTH's *Future Education Principles* (Leif, 2022). It also aims to support lecturers in one of their most important roles, i.e. to "socialize their students into discourse practices of the academic community" (Basturkmen et al. 2014: 443). The guide is rooted in the typical writing genres of a technical university, and it draws on examples of these to explore key areas of scientific language and discourse in English.

In this paper, we introduce *The KTH Guide to scientific writing*, present the initial findings of our evaluation process, and discuss the potential impact of these findings on writing practices and on the development of the guide. We begin by describing the guide. We then discuss a number of other commonly used writing resources. This is both in order to acknowledge the influence of these resources on our work at KTH, and to explain why we believe the addition of a bespoke KTH guide to scientific writing benefits our students, our colleagues, and the institution as a whole. We go on to explain the principles underpinning the KTH guide, and provide some examples which illustrate these. We then discuss the process used to evaluate and develop the guide, a process which has served to spark the beginnings of a conversation among students and faculty about how we write.

DESCRIPTION OF THE KTH GUIDE TO SCIENTIFIC WRITING

The KTH guide comprises an introduction, a glossary of grammatical terminology, and sections on sentence structure, punctuation, text flow, and scientific style. The introduction on the home page outlines the aims of the guide and the principles which underpin it. It also defines "scientific writing" as the highly technical writing "produced by scientists for other scientists" (Hofmann, 2020: 10), comparing it with the less technical "science writing" aimed at a more general audience. We mention how writers might use the information in the guide as a shared reference to inform conversations about language use and writing. We make it clear that questions of linguistic usage are often not straightforward, not even for linguists:

[The KTH guide] may even help to settle an argument when you are working with co-writers or participating in supervision meetings! We don't pretend that there are always easy, straightforward answers to questions of language or conventions, or that everyone agrees on these things. What we try to do in this guide is to suggest why a particular choice may be most suitable and effective in a particular context.

A REVIEW OF WRITING GUIDES AND TOOLS

Many universities have produced their own online writing guides, such as *Purdue OWL* and *AWELU*. Some resources specifically address students (University of Colorado) and some specifically address academics and researchers (University of Edinburgh). These guides typically include information on common genres of academic writing, referencing and language use. The content is comprehensive and detailed, and most academic writers will find information pertinent to their work. However, these guides are written with a university-wide readership in mind, and STEM students may struggle to relate to material which does not fully reflect the technical genres they typically engage with. Creating the KTH guide allowed us to build explanations around examples of text which engineers could easily relate to, often examples of writing produced by KTH students and faculty.

A key handbook for many engineering students and researchers is *The IEEE Guide to Writing in the Engineering and Technical Fields* (Kmic and Longo, 2017). The IEEE guide is characterized by a comprehensive analysis of engineering genres and examples. A particular strength of this guide is the emphasis on writing as a series of choices or “writing decisions”, not simply a set of rules and prescriptions, an approach which also informs the KTH guide. However, the IEEE guide has a great deal of explanatory text, which some students, especially those at the beginning of their studies, may struggle to navigate for self-study or quick reference. In the KTH guide, our aim was to provide short explanatory texts which can be read quickly and easily, and which relate directly to examples provided.

A useful resource for KTH students and faculty closer to the social sciences is the APA style guide. This guide sometimes takes a more prescriptive approach than the KTH guide. For example, it states: “Use a serial comma (also called an Oxford comma, Harvard comma, or series comma) between elements in a series of three or more items. This contrasts with the KTH guide, where this type of usage is presented as more of a choice dependent on context or, sometimes, even personal preference.

A number of practitioners report on the process of creating bespoke institutional guides. Economou and James (2017) designed a “research writing tool” for medical fields. Christiansen et al. (2014) report on the development of a guide for engineers. One question that arose during the latter’s design process was how to encourage staff to use the guide as part of their courses. As the authors state, “[i]f the guide becomes one faculty member’s writing guide rather than a departmental writing guide, neither the authors nor the department will have accomplished their goal” (2014: 4). Indeed, if guides like this are to be integral to “making language visible in the university” (Bond, 2021), there needs to be ‘buy-in’ across university faculty. Moreover, as Guerin et al. (2017) report, doctoral supervisors may receive insufficient guidance on how to support their students in the writing process. We are promoting the KTH guide among all students and faculty at KTH, and using it to facilitate dialogue among them.

In addition to writing guides, a number of editing tools such as Grammarly are commonly used, and innovations such as ChatGPT throw up particular opportunities and challenges in academia. More traditional resources such as dictionaries and thesauruses also play a role, as do sites such as Academic Phrasebank. As teachers, we are open in our discussions with students about these tools, encouraging strategic but critical usage.

PRINCIPLES UNDERPINNING THE KTH GUIDE TO SCIENTIFIC WRITING

We felt strongly that the KTH guide should be rooted in a principled pedagogy. The first principle reflects our aim to situate the guide in the local and international context of KTH. The second principle reflects the view that language and writing conventions are dynamic and diverse in nature. The third principle reflects the notion that writing is a social practice, involving context and writer choice, and “not simply a technical and neutral skill” (Street, 1984, 7-8). Implicit within these principles is the idea that the guide should be an evolving entity, and that the writing community at KTH should have a sense of ownership of the guide. This is also to acknowledge that there are areas where there will undoubtedly be gaps in our knowledge, or misunderstandings about certain disciplinary conventions.

Reflecting the Local and International Context at KTH

A scientific writing community can be viewed as a *community of practice* (Lave and Wenger, 1991) of which newcomers can become active members if offered opportunities for meaningful "peripheral participation". We aim to make the guide relevant both to students as they integrate into the discourse practices of their discipline, and to faculty as they guide their students in this process and develop their own life-long skills. We therefore selected exemplars which reflected typical writing practice at KTH, such as degree projects and research papers. As well as this local focus, we also acknowledge the international context by covering aspects of regional variation such as US/UK spelling. We intend to expand on this and to include discussion of English as a lingua franca (ELF) as the guide develops.

Reflecting the Diverse and Dynamic Nature of Language and Writing Conventions

In order to reflect the diverse and dynamic nature of language, it is necessary to represent language as more than a set of rules and prescriptions, acknowledge variation (social, regional, historical), and indicate where there may be room for choice and individual preference. This approach entails the avoidance of excessive or arbitrary prescription and acknowledgement of the reality of language usage in scientific writing today. The prescriptive-descriptive dichotomy is something which has always been part of discussions about language and language teaching. In simple terms, prescriptivists are interested in telling people how they "ought to speak and write" while descriptivists are interested in talking about how people "actually do speak and write" (Huddleston and Pullum, 2005: 5). According to the leading expert on language change, Jean Aitchison, prescriptivism often means that "invented language rules often get confused with genuine language rules" (1997: 5). One of the aims of the KTH guide is to help writers recognise this distinction, and to understand that even genuine rules may be subject to present-day variation or change over time. This is currently reflected in the guide's explanations, and in the labelling of examples. The guide does use *incorrect/correct* labels where there is a clear grammatical issue, but it also uses other labels in attempt to acknowledge variation and complexity, and to acknowledge where there is a continuum rather than a strict right or wrong dichotomy. These labels include: *problematic/better*; *less formal/more formal*; *wordy/more concise*. The KTH guide also reflects the fact that writing conventions can vary across disciplines and even among individuals. We try to acknowledge where these conventions are not always as transparent or consistent as might be expected, and where they are, moreover, sometimes contested.

Reflecting the Idea of Writing as Social Practice

The KTH guide aims to reflect he idea of writing as social practice, as opposed to a purely technical or neutral skill (Street, 1984). As writers construct a text and construct meaning, they make conscious and unconscious choices in terms of content, organisation and language. These choices are dependent on a range of factors which relate directly to the writer's audience and purpose, institutional power structures, and the dominance and privileging of particular literacy practices (Street, 1984). The KTH guide is intended to provide writers with the knowledge and tools to make informed choices in this context.

Examples from the KTH Guide which Reflect Variation and Writer Agency

Users of a language need to follow certain "genuine" grammatical rules (Aitcheson, 1997) in order to be understood and meet the expectations of readers, and this will determine some of the choices they make. For example, statements in English usually require a subject-verb word order (*the vehicle [subject] is powered [verb] by an electric motor*), and if this rule is broken (*is powered by an electric motor the vehicle*), the text will not make sense or read well.

Other areas of grammar are less straightforward, however, comma use being a good example. Some commas are integral to the meaning of a sentence, and therefore grammatically necessary in a sentence like: *The data, which was gathered over two years, was analysed using various packages.* If the commas were removed, the meaning would change to imply that there was other data in addition to that which had been collected over two years. The guide provides simple rule-based information on this comma use in the section on *Relative clauses*. In contrast, where commas are optional, the guide provides advice which reflects this fact:

It is optional to use an Oxford comma before *and*, *but*, and *or* to separate coordinate phrases and clauses. However, an Oxford comma can often make a sentence clearer by separating elements and reducing the possibility of ambiguity.

We also wanted to be open about the unclear or contested nature of some academic and scientific conventions, as demonstrated by this introduction to active and passive voice:
There is some debate about the role of the passive voice in scientific writing, and writers often receive contradictory or confusing advice about this. Traditionally, passive structures were favoured (Leong, 2020); however, both passive and active structures play a role in modern scientific writing.

A related question, one frequently asked by our students, is whether personal pronouns can be used in scientific writing. The KTH guide addresses this question by contrasting two articles in *The Lancet*, one using personal pronouns, the other using the passive voice, thus demonstrating the acceptable variation that exists in academia, even within the same journal:

Methodologies are often described using the passive voice (often combined with the active voice), underlying the focus on what is done, rather than who is doing it, as in example (1). However, today, it is also common to see methodologies written using *we*, as in example (2). Note that these two examples both come from the same journal, *The Lancet*. It is important to establish if there is a preferred approach in your field and write accordingly.

(1) This retrospective, total population cohort study <u>was done</u> using data from Swedish nationwide registers. […] Two outcomes <u>were evaluated</u>.
(2) In this systematic review and network meta-analysis, <u>we searched</u>, without language restrictions, the Cochrane Schizophrenia Group's specialised register […]. <u>We included</u> randomised controlled trials […].

Having seen these examples, the students can then, as advised here, approach their own field with an open mind to see what is conventional.

CURRENT WORK

Since its publication on KTH's website in August 2022, our focus has been to introduce the KTH guide in our scientific writing courses and trial its content with our students. To this end, we have updated our teaching material with references to recommendations and examples in the guide, and we have created online quizzes on Canvas, our learning management system, which test the students' understanding of the guide's content. The guide has already become an important feature in KTH's provision of training in scientific writing in English, and we are also working to promote its use more widely in the university via colleagues in schools and the library.

While we introduce the guide in our academic writing courses, we have also begun to evaluate its content and usability. We have created a survey using interactive presentation software where we ask the following questions:

1. What can you find in the KTH guide that reflects your current practice as a writer?
2. What can you find in the guide that you think might help you improve your writing?
3. What can you find in the guide that surprises you, or appears to contradict your instincts or something you heard in the past?
4. What would you like to see changed in the guide or added to the guide in order to support you in your writing?

While Question 1 reflects the idea of the guide as something that builds on users' previous knowledge, Question 2 encourages users to explore new strategies that may enhance their writing. Question 3 draws users' attention to the fact that, while some questions concerning language use may have a definitive answer, many others are complex, context dependent, or contested. Question 4 invites users to influence the future development of the guide. The survey is part of an ongoing evaluation process which we hope will keep the guide up to date and relevant to the KTH writing community.

PRELIMINARY RESULTS AND DISCUSSION

We have thus far collected 168 responses (106 bachelor/masters; 50 doctoral; 12 faculty). Here, we discuss a number of interesting themes that have so far emerged from our data analysis. We also provide examples of how we have begun to revise and extend the guide in response to feedback from users.

Is it OK to repeat?

Topics which generated a high number of responses were the use of repetition and parallel structures (structures combining new information with repetition of known information), with 43 mentions in total. Strategic use of repetition, including the use of parallel structures, is advocated in the KTH guide as a means of helping a reader navigate a text easily. Repetition is believed to reduce the amount of processing required by the reader so that they are "freer to attend to the overall message" (Tyler, 1994: 686). Some respondents demonstrate awareness of the importance of repetition and parallel structures, the latter of which, in the words of one respondent, "help the reader understand the message more easily". However, the advice to repeat is sometimes met with confusion or resistance. One respondent stated their reluctance to use these strategies as they were "boring", a comment which reflects a, in our experience, fairly common, and potentially problematic belief that students are expected to display the breadth of their linguistic knowledge over and above conveying ideas in a clear way. Other respondents appeared unsure about the guide's advice to repeat, stating that it is something they were not used to, or, as one stated, surprised to see "so advocated". Another respondent asks:

"Is it okay to repeat the last phrase of [the] previous sentence at the beginning of the next sentence right away?"

This particular question appears to refer to the common given-to-new information structure in English, where the beginning of a sentence refers back to the theme of the previous sentence, repeating or summarising it, before adding new information. This does not necessarily involve the very last phrase of the previous sentence, but it is possible, e.g.:

*Texts are often organised using <u>given-new information structures</u>. **These structures** can enhance the flow of a text.*

The given-to-new principle, with its integral use of repetition or summary, is covered in detail in the guide and was specifically mentioned by 13 respondents, either as something they recognise, or as a new concept, albeit one they may instinctively employ:

"… I have used it before but not knowing the theories."

These responses suggest that better understanding of how repetition functions in a text can help writers to reflect on current practice. This may lead to the adoption of more effective strategies or the reinforcement of currently successful ones.

But I was told something different

Respondents' comments on potentially useful strategies (Question 2) spanned the entire content of the guide, including parallel structures, inclusive language and given-to-new information structure. In response to both Questions 2 and 3, a number of respondents explicitly reflected on guide content which seemed to contradict current practice, or previous instruction or recommendations. Some of these related to issues around repetition, as detailed in the previous section. Some other comments were connected to differences between English and the respondents' first language in terms of sentence structure and punctuation use. One comment related to perceived tensions between writing strategies at school and university:

"I was not aware of the importance of writing concise [sic], as I'm not unfamiliar with trying to push the word limit in schoolwork."

Another respondent appreciated the punctuation section as they had been confused by Grammarly's suggestions on commas. The KTH guide explains where commas are grammatically necessary, or where they are more of a style choice.

Respondents sometimes reacted to parts of the guide where particular academic writing myths were questioned or dispelled. This included some responses to the guide's position on the acceptable use of both active and passive voice in scientific writing, together with the potential inclusion of personal pronouns, which may contrast with prescriptions users have previously encountered. Respondents were sometimes surprised by this information, pleasantly surprised in this particular case:

"Maybe a bit (positively though) surprised by the discussion regarding active/passive voice."

Another respondent was encouraged to hear that active voice may be "better" than passive voice in some contexts, and one faculty member commented on the negative effect that over-prescription or misunderstanding in this area can have on the writing process:

"It is OK to use both passive voice and "we" in academic writing. But many spend time trying to avoid this."

These responses suggest that the KTH guide can be a useful shared resource to help students and faculty explore tricky and contested issues together, and that it can help writers respond to suggested edits from tools such as Grammarly in a critical way.

We know but we don't know!

Faculty members had a particular response to the guide related to their experience in scientific writing and their role as educators. Although they were generally familiar with the contents of the guide, half these respondents appreciated that it provided a summary, "refresh", or one-stop shop, or made them reflect on language and writing issues in a new way. As one respondent commented on guidelines for objective and inclusive language:

"We all know them informally, but the guide puts these down more concretely."

One doctoral student with extensive experience also appreciated the revision opportunities afforded by the guide:

"… I've worked in communication for 20 years. But that doesn't mean I don't need to revise [these writing strategies] again! :-)"

However, some aspects of the guide were in fact new to some of these experienced writers, or at least in the way that they were presented in the guide, including inclusive writing, restricted use of the pronoun 'one' (compared with Swedish, for example), and the use of Latinate words to increase formality.

These responses suggest that the KTH Guide can clarify or extend faculty literacy practice, and also help faculty articulate linguistic matters in discussion with students.

REVISING THE KTH GUIDE TO SCIENTIFIC WRITING

Revisions to the guide are largely based on responses to Question 4. These include:

- Adapting the preamble at the start of each section to conform to KTH guidelines on accessibility;
- Developing the section outlining conventional use of active and passive to make the link to personal pronoun use clearer;
- Adding more examples of gendered or biased language along with more inclusive alternatives;
- Incorporating a note suggested by one doctoral student (working within a more social science than technical tradition of robotics) regarding the convention-challenging use of 'her' as a general pronoun;
- Adapting the tone of the text in places to incorporate more caution around usage guidelines, reflecting comments we received on variation across disciplines.

A significant issue for respondents (Question 4) related to difficulties in navigating the guide and the lack of an integrated search function. We are currently exploring these issues with KTH Digital Education.

CONCLUSION

The KTH Guide to scientific writing is an ongoing project, the aim of which is to create a writing tool which meets the diverse needs of our university writing community, and which, with the input of this community, will evolve over time to better meet those needs. We are conscious that the creation, use and ongoing evaluation of the guide affords a unique opportunity to make language and the way we write more visible and more widely discussed across the university. Currently, we only have a small number of responses from faculty. It is important to collect more data from this group and also use this process to promote use of the guide as a shared reference on KTH programmes.

We are at an early stage of data analysis, so are limited in terms of the conclusions we can draw at this time. However, the responses we have so far analysed suggest that the guide:

- Can help students to reflect on current literacy practices, promoting change as well as reinforcing positive strategies;

- May constitute a useful shared resource for students and faculty navigating tricky or contested areas of language and discourse, while also promoting critical use of writing tools such as Grammarly;
- Can support faculty development and help faculty articulate linguistic matters when discussing student writing.

As we collect and analyse more data through questionnaires and focus groups, we will be able to better understand how the guide is used and how it can be further developed to meet the needs of scientific writers.

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THE STUDENT FLIGHT DATA RECORDER – BUILDING A CULTURE OF LEARNING FROM FAILURE

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ABSTRACT

This paper presents the results of a collaborative project initiated by first year teaching staff and study counsellors within the Aerospace Engineering Bachelor's programme at Delft University of Technology aimed at tackling the challenge of stimulating critical self-reflection and coping with failure. This project took the concept of a study planner and reflection journal and turned it into a symbol synonymous with learning from failure – the aircraft Flight Data Recorder. This symbol was combined with animated storytelling to introduce and explain the purpose and function of the Student Flight Data Recorder (SFDR), after which the usage of the resource was scaffolded by student mentors. Acknowledging that some students would not feel compelled to use a resource that was not required, a moment of intervention was offered at the completion of the first academic quarter after the first round of final exams. Overall, the project team has observed that the project has created more awareness and discussion about these topics within the student population. The next step in the project is to add an educational researcher to the project team with the intent of carrying out quantitative research into the effectiveness of the tool.

KEYWORDS

Self-reflection, Failure, Self-determination, Standards: 7, 8, 11.

INTRODUCTION

Many of us have been in the situation where we have observed that student learning and success has been hindered by deficiencies in their ability to plan, self-reflect, and learn from their own mistakes and failures. Students tend to focus on grades and the need to succeed rather than the process of learning and what they can learn from both their successes and failures. Furthermore, students see their instructors as assessors that are there to judge them, creating a strong deterrent for sharing authentic self-reflections that may expose or highlight their own perceived deficiencies. This creates a challenge for meaningful self-reflection exercises meant to address these deficiencies - how can we get students to perform meaningful self-reflection without triggering their student mind to simply reflect back what they think the teacher wants to see?

With this in mind, a team of study counsellors and academic teaching staff embarked on a project, known as the Student Flgiht Data Recorder (SFDR), to stimulate a culture of critical self-reflection and learning from failure without turning it into a course assignment. The project specifically targeted incoming first year bachelor students and their struggles in navigating the transition from high school to university. Based on collective experiences in teaching and mentoring students, the project team defined the ambition that the SFDR should help:

- Instill a sense of personal responsibility for learning and development;
- Reinforce the importance of time management, self-discipline, and critical reflection in study success;
- Destigmatize the word/concept of ”Failure”;
- Equip students with the tools and mindset to learn from failure;
- Leverage the intrinsic motivation/ambition present in students entering their study programme.

It is important to note that this project was initiated based on the experiences of the practitioners involved (Rans & Teuwen, 2021; Saunders, Breuker, Rans, Schuurman, & Staalduinen, 2018; Saunders-Smits et al., 2020; Schuurman & Rans, 2022; Schuurman, Saunders-Smits, & Rans, 2018). It was not setup as an educational research project aimed to gather quantitative educational research data. Neither was it formulated based on an extensive review of the educational literature. However, the authors feel that the aims of the project align well with the intentions of the CDIO Approach (Crawley, Malmqvist, Östlund, & Brodeur, 2007). Specifically, the project aims to integrate elements of personal growth and reflection with discipline-relevant content (Standard 7), help students identify learning opportunities from their own failures (Standard 8), and provide formative feedback on the importance of soft skills in the educational journey (Standard 11). For this reason, this paper will outline the overall approach and thought process behind the Student Flight Data Recorder project, with the intent to engage the CDIO community. As formal conclusions based upon quantitative research data cannot be made, the paper concludes with a reflection on the next steps needed within the project.

THE STUDENT FLIGHT DATA RECORDER PROJECT

This project started with the concept of a study planner and reflection journal that was heavily inspired by the Passion Planner series of notebooks (https://passionplanner.com/). These notebooks creatively mix a traditional agenda/planner with various goal setting and reflection exercises that aligned with the time-management and critical reflection ambitions of the project. Sample pages from the SFDR can be viewed at https://www.calvinrans.com/sfdr. The development of this study planner and its planned utilization was governed by three guiding principals:

1. Use of the SFDR is encouraged, but not mandatory, to avoid making it an assignment.
2. The contents of the SFDR are confidential to the student. They are encouraged to discuss and share only what they are comfortable with.
3. Emphasis should be placed on failure being something one experiences rather than something one is.

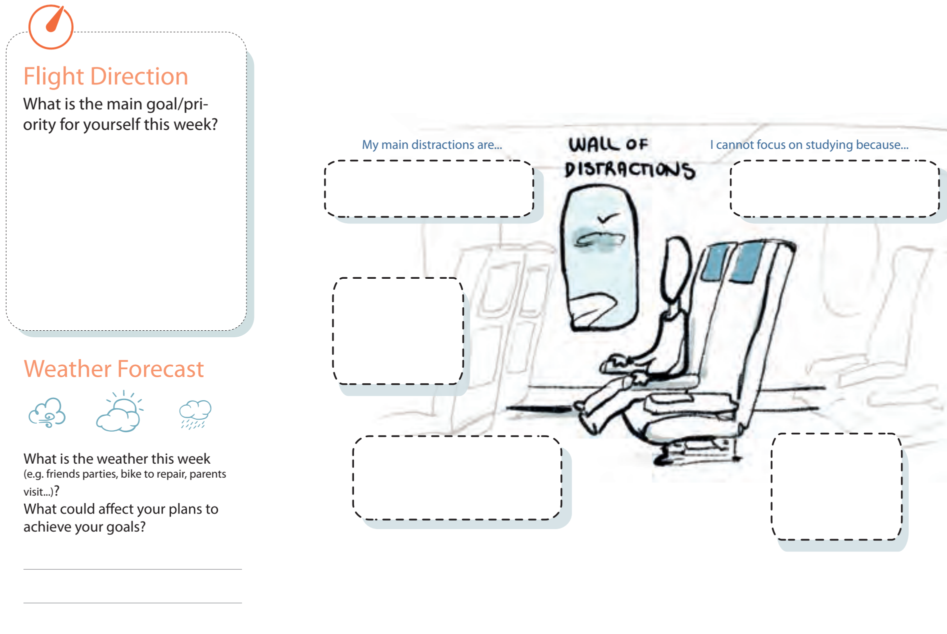

Figure 1. Examples of reflection activities connected to the aerospace theme: Flight Planning for weekly goal setting (upper left), Weather Forecast for identifying risk factors for meeting the goals (lower left) and an exercise for identifying distractions in the study environment (right).

By not making the use of the resource mandatory and further emphasizing that the reflections within it were confidential and for the student only, we wanted to create a safe space for students to engage in meaningful critical self-reflection. However, it was also acknowledged that there was a risk that students would not feel compelled to use a resource that was not required or could earn them points towards their grade. To tackle this conundrum, the project team had to look at how to connect and activate students' intrinsic motivation to use the resource in the absence of the extrinsic motivation provided by grades. The first element of this was relatively easy given the context of its usage in an aerospace engineering faculty. All incoming students have a keen interest in aircraft and spacecraft, providing the opportunity to relate various activities within the planner to this theme in a fun manner as shown by some examples in Figure 1. In addition to this, the project team focused on four different elements to help scaffold and reinforce the usage of the resource by students, known as the symbol, the story, the struggle, and the intervention. In the following sections, these elements and their connection to activating intrinsic motivation within students will be discussed.

The Symbol

Symbols hold a power that helps shape and express the identity of individuals or groups (Erel-Koselleck, 2004). It doesn't take more than a short walk around your city or campus to see this first hand. You would see social community's joined through brand loyalties, sports team allegiance, hobbies, and even interests that are identified or associated with particular symbols and/or artifacts. The sense of belonging and camaraderie that is derived by being within such a social community provides a significant intrinsic motivation for individuals who belong within that community. Thus, having a strong symbol for this project can help anchor the project ambitions and help form a sense of community around them.

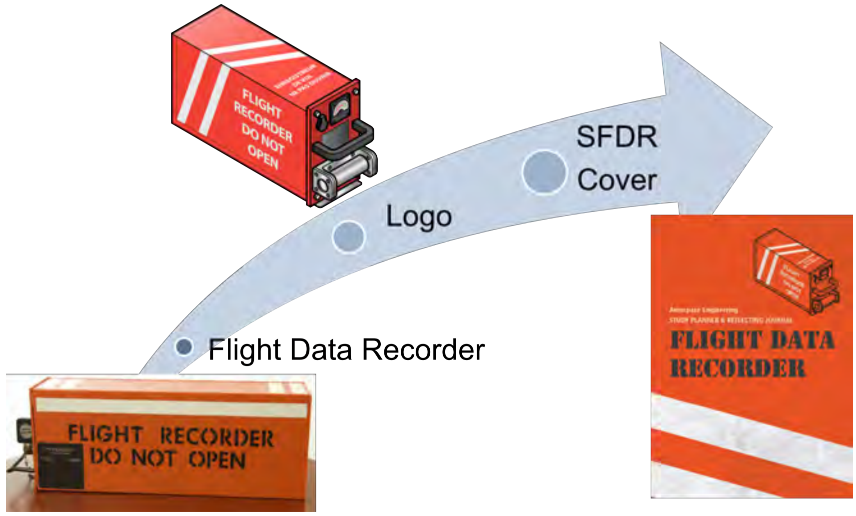

Figure 2. Flight Data Recorder symbolism transfered to the student flight data recorder

The symbol chosen for the project is already alluded to in the name of the project - a Flight Data Recorder, or FDR. The recognizable imagery associated with an FDR was translated into a logo and cover design for the SFDR as shown in Figure 2. It is quite an appropriate symbol for the project given that *1)* it is a recognizable aerospace artifact with an ubiquitous association with failure, *2)* it is used to learn from failures, and *3)* its contents cannot be used to apportion blame or liability in case of a failure.

The first two points will be treated as self-evident; however, the third point and its importance is worth discussing further. Most people outside the aviation safety sector do not realize that use of the data on a FDR is protected (see 14 CFR § 91.609 (*Aeronautics and Space.*, 2021)). This may at first be surprising, but its need becomes obvious when you realize the scenario it places pilots and other flight crew - a workplace under constant surveillance of microphones and other sensors. Such a workplace could be considered a huge invasion of privacy without the presence of strong agreements on the usage of that data. Luckily, such agreements are in place, and such data is permitted to be collected and used only in the context of an Air Safety Investigation and not a Judicial Investigation (*Annex 13 - Aircraft Accident and Incident Investigation*, 2016).

If you consider the vulnerability associated with a critical self-reflection by a student, a similar need for trust and strong agreements between students and staff is clear. The authors feel that this is one of the major failings of self-reflection exercises that are directly reviewed and assessed by teachers. In the absence of this needed trust, students tend to reflect what they feel the teacher wants/expects to see to avoid the risk of exposing themselves through their own struggles and failures, circumventing the intended purpose of the activity. This is the motivation behind the first and second guiding principals of the SFDR project, and the FDR provides the perfect symbol to encapsulate this.

The Story

To complement the symbol of the SFDR, the use of storytelling was used to communicate its function and intended use. This was achieved using an online animation software (www.Vyond.com). Although it can be difficult to fully articulate the power a story holds, the following perspective

SCAN ME

https://youtu.be/tvVu4sBhmjk

Figure 3. SFDR animated story for introducing students to the project

from Fisher (1989) provides some useful insight that is applicable here:

> ”We tell stories to give order to human experiences and to induce others to dwell in them in order to establish ways of living in common, in intellectual and spiritual communities in which there is conformation for the story that constitutes one’s life.”

This underpins the ambition behind creating a story for the SFDR project. We wanted to create a relatable story that aligned the ambitions of incoming students with the well-known challenges of adapting to university studies in a way that fostered a culture of learning from failure and critical self-reflection. To achieve this, a team of first year lecturers and student mentors defined a story which makes an analogy between university as a journey to their career ambitions and a flight from one destination to another. Only in this flight, it is not possible to be a mere passenger. The flight is only the end of the journey that begins with the student needing to learn and train the skills required to pilot the flight themselves. It is difficult to explain all of the elements of the story without ruining the story itself, so the reader is first directed to the QR code in Figure 3 to view the animated story firsthand.

It is important to point out the contribution of the student mentors within the project team that helped ensure the story was engaging and effective from a student perspective. Several key details of the story that emerged based on their input is important to highlight:

- Male and female avatars, and extroverted and introverted personas were used to maximize the relatability of the student-based characters in the story
- The concept of a learning community where teachers and peers all help each other was embedded in the story
- Lighthearted but relatable examples of mistakes and failures were introduced to help student connect with the role of self-reflection in learning
- The overall story remained positive and encouraging from a student perspective despite the difficult touchy subject matter of failure and personal responsibility.

In addition to these contributions, efforts were made to make the symbol of the FDR evident in the video (reinforcing guiding principles 1 and 2) and to destigmatize failure (guiding principle 3) throughout the video.

The Struggle

With the symbol and accompanying story to connect students to the purpose and usage of the SFDR in place, the next stage of the project occurs - the Struggle. This stage has a bit of a double meaning in that it refers to the struggle is felt by teachers and student mentors as they observe some students not engaging with the project and to the overall struggle of students learning to cope and adapt through this transitional phase of their lives. It comes as a natural consequence of guiding principal one of the project - use of the SFDR is not mandatory.

Although its use is not mandatory, this does not mean its use is not encouraged. The cohort of incoming bachelor students are placed in groups and assigned a student mentor to help guide them in their first month of their studies. Those student mentors receive training in mentoring and guidance of students, are briefed on the purpose and intended use of the SFDR, and are asked to engage their students in discussion of the exercises and activities within it and encourage its use. Student mentors have given feedback to the project team on the usefulness of the resource simply in terms of providing a fun and almost gamified basis for discussing the struggle to adapt to university within their mentor groups.

Teachers in one of the first year courses also indirectly do their part to reinforce the relevance of specific reflection exercises within the SFDR. A conscious decision was made not to have teachers directly refer to the SFDR in their courses, as this could create a false connection between the SFDR and a particular course, or a false expectation that use of the resource was required for that course. Direct reference to and discussion of the SFDR was contained within the mentor groups. Instead, the teachers were informed of the nominal timing of specific self-reflection exercises within the SFDR and encouraged to engage students in related topics naturally within the context of their own teaching. For example, in one week approaching the exam period of the academic quarter, students were confronted with a self-reflection exercise where they needed to assess their self-study space and the possible distractions contained within it (see Figure 1). In the same week, teachers within the Engineering Statics course sparked a class discussion on effective study practice.

The Intervention

Acknowledging that some students would not feel compelled to use a resource that was not required or graded, a moment of intervention was planned after the first final exam period of the academic year. This intervention was setup as a lunch lecture entitled *Engineering Success out of Failure*, which was designed to help students reflect on how to learn from failure by examining the purpose and process of an Air Safety Investigation. Students were unaware beforehand that this lecture had any connection to the SFDR they had recieved at the beginning of the year, nor did they know the lecturer (Calvin Rans) was connected to the project either.

The first aim of the lecture was to help students see failure as something you experience, not something that you are. Most students entering the Aerospace Engineering Bachelor programme were the top of their class in high school and likely did not struggle to do well there. If they failed a course or exam, or even passed but with grades far lower than they have ever received, they often see themselves as a failure, not having developed the skills to cope and respond to this type of event. To try to dispel this belief, the lecturer begins the lecture with a personal story of their time in university when they failed an exam. Having a university professor

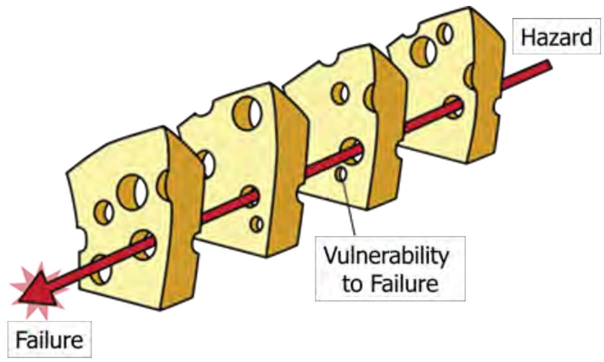

Figure 4. Swiss Cheese Model illustrating multiple vulnerabilities/causes needed for failure.

- a figure of academic success in many students minds - describe a moment of failure in their academic past has a profound effect on many of the students. It helps them see that such a moment doesn't necessarily define them, and the failure can simply be a moment or event, if it is responded to in the right manner.

The second aim of the lecture is to discuss how to respond to failure in a professional manner through examining how an Air Safety Investigation is carried out. The authors would like to make clear that we do not equate the gravity of an aviation accident with that of a student failing an exam or a course. However, both types of failure can elicit strong emotions and create an overwhelming desire to apportion blame for the event. With this commonality, the objective of an Air Safety Investigation as stated in *Annex 13 - Aircraft Accident and Incident Investigation* (2016) carries a lot of relevance:

> ”The sole objective of the investigation of an accident or incident shall be the prevention of accidents and incidents. It is not the purpose of this activity to apportion blame or liability.”

The importance of this objective is discussed in detail, particularly with respect to ensuring the willing cooperation of all parties involved in the safe operation of an aircraft. Additionally, a simple conceptual model known as the Swiss Cheese model (see Figure 4) is also presented to them to highlight that failures are rarely caused by a single event, but require vulnerabilities across multiple layers of safety to permit a failure to occur. This is then reflected back into the student experience, where we challenge students to think of their own failures like Air Safety Investigators. They should aim to prevent future failures rather than fixating on their desire to blame for the present failures, and recognize that there are other vulnerabilities they may identify and are responsible for.

The last aim of the lecture is to iterate the importance of data and collecting data for an investigation. The function, importance, and agreements behind the FDR in the context of an Air Safety Investigation are discussed. It is at this moment that the lecturer then refers to the SFDR, and reveals their part in bringing the project to fruition. Students are challenged to review their own data recorder in a bid to identify possible vulnerabilities and make recommendations to themselves to remedy them. The lecture is closed off by a harsh but necessary truth - if their SFDR is empty, then the data recording process was faulty, and they should make recommendations to themselves to find an effective way to critically reflect and gather the data they might need to help investigate future failures.

EARLY RESULTS AND NEXT STEPS

The following is a reflection from one the of the student mentors that was responsible for encouraging the usage of the SFDR with their mentor group.

> As a first-year mentor, you are responsible for 22 students. You meet them at the beginning of September and from that point onwards you see them once a week for the first 6 months of their university life. Most of the students have a lot of questions and at the same time, as a mentor, there is a lot of information to relay. Staff and Academic counsellors within the university prepare you with what is important, however having something like the SFDR helps students not feel so overwhelmed. The SFDR condenses the essential information and makes it easily accessible to each student.
>
> Every mentor has their own method of communicating but it is natural that sometimes we forget to mention something. Therefore, having all the most important parts written and given to each student prevents a significant amount of miscommunication and stress on the mentor's part. In addition to this, it makes explaining many of the concepts easier as well. For example, explaining modules can be quite complicated; on the other hand, asking them to turn to the curriculum page in their logger and work out their final grade if they got a 6 in dynamics and 8 in statics proved to be a nice icebreaker.
>
> As a mentor I often think about what I would have wanted in my first year and the SFDR is a great start. At first, I didn't think I would use it but found myself using the same template for my personal exam study schedule as that proposed in the SFDR. So even if the students didn't use the book completely, it's still a source of inspiration.
>
> I found that some of my students would stop using the SFDR after the first exam period (around 2 months in). This makes sense, as that is when most students start to settle in and become accustomed to the TU Delft ways. Some students found it quite "cheesy" to reflect on their week, but others benefited from it. Personally, I believe that, having the resource and the support available, even if you don't necessarily need it, makes all the difference.

From this reflection, it is evident that the SFDR became a useful resource for students and mentors. Although it did not always become a pervasive tool that students used throughout their entire academic year, it served as an effective symbol/artifact to facilitate discussion on personal responsibility and critical reflection within academia.

The instructor perspective is limited mainly to the experiences from the intervention lecture. It was found that this intervention was extremely powerful and effective, and gave the SFDR a renewed sense of purpose, both as a resource and a symbol for the students education. After the lecture, many students approached the lecturer thanking him for framing failure in such a constructive way. Most had never learned to deal effectively with failure, and were stuck in a state of feeling inadequate or angry, and the intervention helped them see that they needed to put these emotions aside and investigate what vulnerabilities contributed to their own failure, and find ways to mitigate them and prevent future failures. In the weeks and months following the intervention, the instructor also experienced a rise in the number of students approaching him to discuss their own study habits and strategies, which was taken as evidence that the principals instilled by the SFDR project continued well after the completion of the cycle of the project.

Although the project team feels the project has been a success based on their own observations, there is a desire to better quantify its effectiveness. As a result, the next step in the project is to engage with educational researchers to design surveys and other monitoring tools to gain the data necessary to verify (or disprove) this perception.

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Helena Momoko Powis is a Masters student at Delft University of Technology's Faculty of Aerospace Engineering. Following the profile, Space Engineering. Member of the faculty student council and founder and chair of Artemis - The space track study society. Active student teaching assistant since 2020. Momo hopes to continue her studies with a thesis on test methods of Cube Satellites while continuing to pursue a career in academia.

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PROJECT SEMINAR – RECONSTRUCTING THE CAPSTONE PROJECT PROCESS

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ABSTRACT

The capstone project (CP) process is an essential layer on the path towards an engineering degree. Typically, the purpose of the CP is to build an actual product prototype. In practice, the process of guiding the CP is less structured than a standard course. This is due to the project's scope and span, the interaction between the student and the academic supervisor and the exogenous workload of the student. The CP process thus requires the academic system to provide a combination of creative, professional guidance and, at the same time, strict management of the process. This paper outlines a methodical way to conduct this complex and challenging process, which we have adopted and refined in the last three years and shares some observations we have made during this period. The essence is the separation between the content and procedural aspects of the project. This contrasts with how CPs were previously managed, where the guiding academic staff were responsible for both aspects. This separation standardizes and optimizes the process and is carried out parallel to the execution of the projects. The main change in the curriculum is the addition of two dedicated courses spanning the last three semesters of studies called “CP Seminar 1” and “CP Seminar 2”. These seminar courses are guided by a team of two professors, who meet with students every two weeks, working toward well-defined and structured milestones. During the courses, students develop an understanding of the conception, design, implementation, and operation of the product they develop as their CP. Thus, greater control, and monitoring of the progress of the students in the process is achieved by the supervisors, the seminar team, and the students themselves. The courses frame the CP process and facilitate strict milestones, standardized documentation, and substantial validation.

KEYWORDS

Teamwork, Innovation, Engineering Problem Solving, Capstone Project, Academic Project Management, CDIO Standards: 2, 3, 5, 8, 11

INTRODUCTION

The capstone project (CP) culminates four years of engineering study. The first three years consist mostly of frontal courses, which provide the student with components of theoretical knowledge in various subjects of the academic career, along with several hands-on courses like micro-controllers lab, which provide hardware and software design practices. The CP phase integrates several of these components of engineering knowledge with the aim to design, build, and test a prototype system. As a goal, the prototype system should somehow refer to a specific problem and provide a solution. The CP process simulates, in a summarized way, the product development process in the industry. In view of this, the CP is a critically important phase in the framework of a young engineer education. The CP is usually carried out during the 4th year of studies.

In the literature, there are several reviews of implementing the CP in engineering studies. For example, Roth, et al. (2019) share experiences of a refinement of the Electrical and Electronic Engineering (EE) curriculum involving the integration of design content throughout the program. A direct benefit is exposure to a variety of technological advances so that they perform better on their CPs. Minaie, et al. (2022) present the detailed content of the EE curriculum at Utah Valley University, which includes two two-semester capstone design courses: Capstone I and Capstone II. The faculty advisor meets with each team project individually on a weekly basis on a regular schedule. The two capstone courses are designated as writing enrichment courses that include not only writing assignments but also writing instruction as major components. Other reviews appear with respect to evaluation (Farrell, Ravalli, Farrell, Kindler, & Hall, 2012), methodology (Shurin, Davidovitch, & Shoval, 2021), and experience (Umphress, Hendrix, & Cross, 2002), particularly in Software engineering.

This paper describes some aspects of the CP experience accumulated in recent years in the EE department at Shenkar College and the innovation included in the process. As a basis for understanding the change in the EE curriculum design, the CP follows a 3rd year pre-CP course called “Electronic Product Development”, which was presented in detail at CDIO2022 (Gal, Furman, & Weissman, 2022). This course summarizes the main aspects of the product development process, thus preparing students for the challenge of carrying out a successful CP.

Previously, until three years ago, the CP process in the EE department spanned approximately one academic year. During this period, each group of students was guided by an academic guide (AG), whose engineering background is suitable for the respective CP subject. The AG guided the CP, starting from the conception of an idea and concluding with the final presentation. We call this frame of reference - "the single AG process".

With the single AG in the CP process, there are inherent challenges in the standardization of the CP process that determine the path the CP takes: 1) the AG's personality and method of work: for example some AGs are more permissive than others; 2) the intensity of the interaction between the AG and the student: if they set regular weekly meetings or only meet when the students request it; 3) the external limitations of the students: many of the students work part-time parallel to their study, so the time to work on the project is more limited; and 4) time constraints of the AGs: there are AGs who also work in other places, and some of them have positions that limit the guidance time. This results in variability in the nature of the CP process, as opposed to the CP content, which is in addition to the inherent unevenness in the level of submitted CPs, attributed to the student's efforts and academic qualities.

In addition to the integrative implementation of engineering concepts, a successful CP requires, among other things: 1) strict adherence to a common set of synchronized milestone schedules, 2) provision of standardized documentation on time, and 3) sufficiently detailed (qualitative and quantitative) validation and test results. Considering the challenges mentioned above, fulfilling these CP requirements reveals gaps and shortcomings and illuminates the need for profound structural and perceptual change. By addressing the challenges and gaps found, the CP process can also be used to reduce inconsistencies, while better preparing students for their professional role in a changing environment.

Single AG guiding of CPs has been practiced for years in our EE department, as noted above. This often resulted in an unequal level and time scale in the CPs submitted. About three years ago we concluded that the existing CP process requires restructuring. Basically, the CP process has been separated into two parallel channels: 1. Content-wise channel: guided by the AG, as before. 2. Process-wise channel, which consists of the incorporation of two seminar courses to the EE curriculum, that synchronize and standardize the components of the CP process. It should be noted that for this purpose, a method previously developed and used in software engineering at Shenkar College was adopted, but modified to adapt it the specific needs, characteristics, and skills of the EE profession.

The purpose of this paper is 1) to provide a description of the two-channel CP and 2) to present and discuss the main benefits of this restructuring. Broadly speaking, these benefits concern the quality of the submitted projects, the skills acquired by the students during the CP seminars, as well as their feedback at the end of the CP seminars.

SEMINAR'S DESCRIPTION

Overview

Students prepare the CP along two frontal courses: Capstone Project Seminar 1 (CP Seminar 1), spanning a period of one semester, taught in the second semester of the 3rd year, and Capstone Project Seminar 2 (CP Seminar 2), spanning a period of one year, taught throughout the students' fourth academic year. Both courses are mandatory. The meetings are one every week or every two weeks, depending on the task that the students must prepare. For a student to be included in the CP Seminar 1, the student must have completed all the required prior courses in the curriculum. A student can participate in CP Seminar 2 only if he has successfully completed CP Seminar 1, such that the year of completion of the CP Seminar 2, and hence the completion of the CP, is the year of completion of EE studies.
CP Seminars 1 and 2 are conducted as a form of face-to-face lectures accompanied by demonstrations, presentations, brainstorming, assignments, and feedback. At the beginning of each seminar, the students receive a complete schedule of all frontal meetings, assignment submissions, presentations, and events they are required to participate in during the upcoming seminar period. In this way the students can plan their work in advance.
CP Seminar 1 is a framework for thinking, conceiving, and presenting ideas for the development of projects, while in CP Seminar 2, the students design, implement and operate real-world systems and products for the capstone project. The phases of the CP Seminar 1 course comprise of: 1. the identification of the students' fields of interest; 2. the formation of project groups; 3. the conceptual ideation of the product; and 4. the matching with the academic guide. During CP Seminar 2, the students undergo the following phases: 1. understanding customer needs and use-case and defining product requirements accordingly; 2. designing the product from high-level architecture down to detailed technical design; 3. validation plan preparation; 4. alpha and beta product version implementation of the product; 5. presentation and demonstration of the product; 6. College exhibition of the project; and 7. writing of a project book, and defending the project in front of an academic jury. The stages of both seminar courses are represented in Figure 1, which shows the flow of the phases as the project advances, as well as the outcomes of each phase. In addition to the formal stages, reviewed in the following sub-chapter, students receive skill development lessons, such as speaking in front of an audience and time management. Future versions of the course will include technical writing lessons. The acquired skills, as well as the qualification methodology, will be reviewed in a separate subchapter. The last subchapter will review the outcomes of these courses in the last two years.

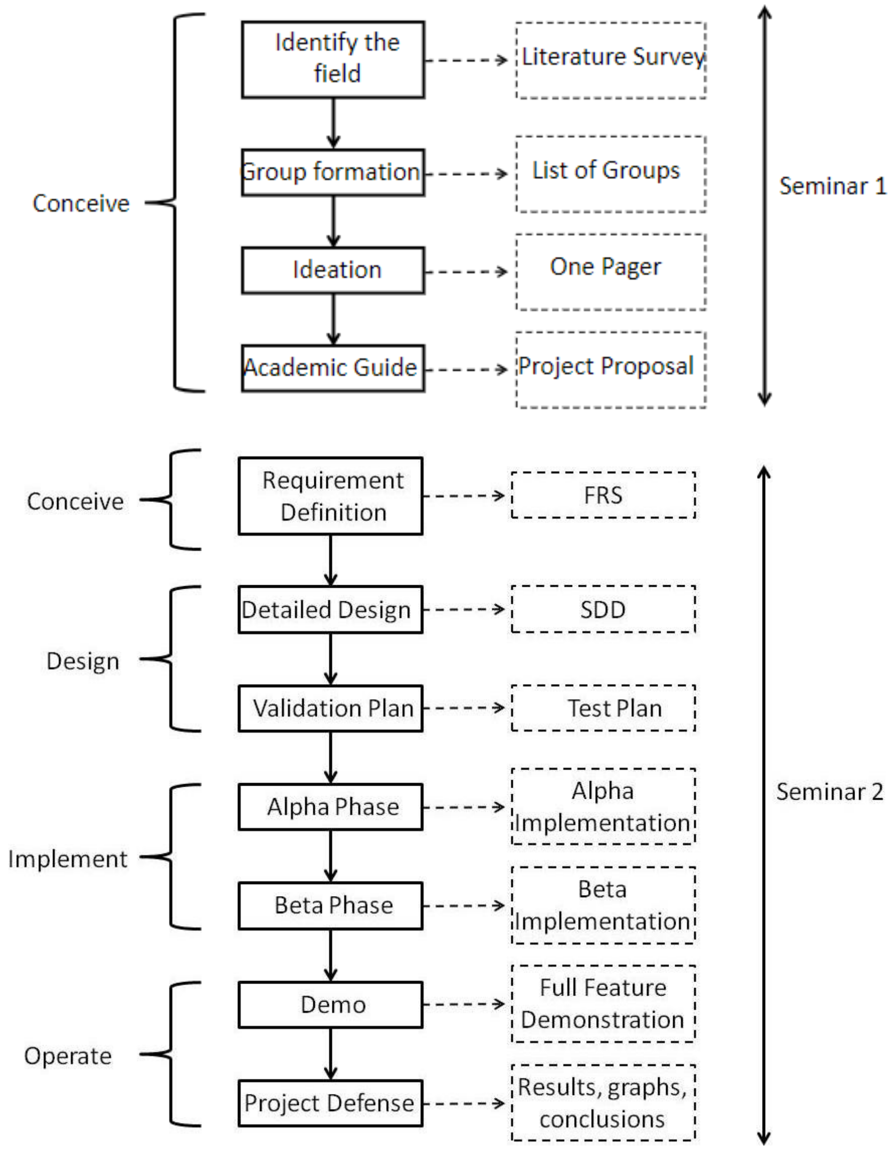

Figure 1. Phases of the CP Seminar 1 and 2 courses and the outcome of each phase, FRS=Functional Requirements Specification, SDD=System Design Document.

Explanation of the CP Seminars' phases

In general, as mentioned above, the CP Seminar courses follow the conceptual framework of the CDIO syllabus (). From this perspective, the phases of the courses are reviewed in detail below.

The phases of the CP Seminar 1 course are:

1. Understand the complexity of CP: In this initial phase, the students go through the process of identifying a field in which they want to get involved and specialize in their CP.

2. Form groups for the project: This step is critical to understanding the connections between team members and the project, the division of responsibilities, the strength of each student, and the common denominators among project participants. At this stage, students strengthen their understanding of teamwork. At the end of this period, students are encouraged to work

in pairs. However, we allow few students to work alone on the project, being aware of the "Individual Contributor" type, recognized by Intel corporation as types which work best alone.

3. Ideation and topic approval: At this stage, the students go through a process of ideation and initial research to formulate an idea based on the chosen field. The students practice skills such as asking questions, research skills, understanding other-worldly areas such as the social, economic, and ecological aspects of a product. They learn to identify a problem and think of an effective way to meet the challenge through the development of an engineering product that includes electrical and electronic components. The idea for a capstone project must meet the criteria established by the department for a capstone project for EE career. The students will focus on finding and selecting a suitable capstone project, according to the following criteria: a) The project requires technological research to find a solution to a defined problem, b) The project requires an engineering scope and complexity of research work, characterization, design, implementation, operation, and significant academic and technical writing.

4. Matching an academic guide: In this phase, the students receive an academic guide for the project and begin to formulate an applied solution. The students learn how to write a capstone project proposal, features of scientific writing, time management, and management skills. At the end of the CP seminar 1, the students receive a foundation for the next phases of the project that will be reflected in the CP seminar 2.

After the project teams have chosen and defined a topic for their projects during CP Seminar 1 and having written their project proposal document, the students begin the process phases of design, implementation, and operation, in the order indicated. These are conducted during CP Seminar 2 and are accompanied by a series of technical documents that are similar to those used in the industry.

The phases of the CP Seminar 2 course are:

1. Definition of functional requirements: in this phase, the student must go deeper into his general project proposal and think about the detailed characteristics of the project, that is, the product. This cannot be done without a deep understanding of the problem, need, and challenge that the project is designed to solve. Additionally, students must define the typical user who will use their product and outline possible user scenarios. Once the student has the use case scenarios, he can derive a list of functional requirements. A common mistake is to confuse the functional requirements with the technical implementation. Therefore, students are advised not to go into technical details, but to stick to the functional requirements from the point of view of the typical user. This entire process is submitted as a Functional Requirements Specification (FRS) document and must be approved by the AG of the respective project. Additionally, the teams prepare a PowerPoint presentation containing the highlights of the FRS document and present it to the class in a ten-minute time slot. Extra time is allocated to each group for questions and answers from the audience, as well as constructive feedback from the course instructors. This concludes the "Conceive" part of the CDIO stage. The next stage of CDIO is the "Design" stage and consists of two phases: the design of the hardware and software architecture, and the development of a detailed validation plan to test the quality of the design.

2. The design of the hardware and software architecture: The first step is the design itself, which is submitted in the System Design Document (SDD). The design consists of defining the architecture of the system, which is a definition of the subsystems (modules), their functionality, and the data and control signals that flow between them. Note that the architecture diagram should not include implementation details, but rather focus on the functional role of each module. In conjunction with this, students must describe a detailed sequence of events that the system handles, specifying the partition with respect to modules. The next step is to define the structure of the database that the software will use. This is mainly a description of the

contents of the database table and the relationships between them. The main and arguably the most important part of the SDD is the detailed design section. Unlike the system architecture document, this document should contain a detailed description of the actual components, which provides enough information for R&D engineers to implement at a later stage. Last but not least is the Graphical User Interface (GUI) subsection. Most of today's projects involve some form of data collection from system hardware using a mobile app. The application often processes the data and presents it to the user in graphical form. Therefore, the presentation of the mobile application screens is essential for a comprehensive understanding of the project system as a whole.

3. Once the system is well defined and designed in detail, the students must write a functional validation test plan to ensure that their design works in full compliance with the functional requirements defined in the FRS document. In addition, an engineering validation should also be planned to verify the operational limitations of the system. The teaching of the validation methodology is carried out by an industry expert, who also advises the teams as they progress through the preparation of the validation test plan. After receiving the basic validation methodology from the expert, the students must prepare a mini plan for peer review. They present it to the class and to the expert, to receive constructive feedback and comments on their plan. This feedback is helpful to both the reviewed teams and the listeners teams, in refining their test plan for the final validation meeting. At the final validation meeting, each team presents the completed test plan to a jury of EE department academic staff. It should be noted that the final validation tests presented to the jury do not necessarily have to be fully implemented at that stage, but rather show the infrastructure to test and validate the system. The complete test plan must be fully implemented by the time of the presentation and the demo stage, which will be at a stage close to the delivery of the CP. The final validation meeting finishes the "Design" stage, and the teams are now ready to move on to the "Implement" stage.

The "Implement" stage, in accordance with CDIO process, is made up of two phases: Alpha Phase and Beta Phase.

4. The Alpha Phase: It is an implementation and testing of several product-specific features, mainly those that carry a risk to the success of the product, trying to adhere to industry standard nomenclature. For example, in a greenhouse project, the students wanted to use a light-gathering optical system, which was supposed to channel sunlight from the outside into an indoor chamber, where the plants were located. The optical system was complicated and beyond the scope of the students' prior knowledge. This feature is a classic risk factor and should be implemented and tested at an early alpha phase, before other less demanding features. The alpha implementation is accompanied by a document that describes the features that are implemented and tested at this phase.

5. The following stage is the Beta phase: This phase contains most of the features, making it a usable product for potential users. Unlike in the industry, where beta testing is carried out by external users, the students' beta phase is an internal phase. Since the students only have a single prototype of the product, they cannot distribute it to external users for evaluation. At best, they can test it among a limited circle of friends and family. In this phase, the product (capstone project) is mature enough to be ready for the final demonstration, which takes place at the end of the academic year.

The last phase of the CP Seminars, and according to the CDIO framework, is the “Operate” phase, which includes the final demonstration of the CP, and the submission of the CP book that culminates in the defense of the entire project.

6. In this demo phase, the teams prepare a fifteen-minute PowerPoint presentation, followed by a physical demonstration of the full functionality of the product. This presentation takes place in front of a large forum of 3rd year students, Shenkar College academic staff and

industry experts. From the demo podium, the now fully functional products are transferred to an annual showcase of capstone projects hosted by the college for all campus departments and guests from industry, family members, and more. The exhibition is open for two weeks, and visitors from other departments, as well as from outside the university, are welcome. Projects are photographed and featured on the Shenkar College website.

7. The almost final step is the writing of a CP book and the preparation for the most crucial phase: the defense of the project. The CP book is a comprehensive technical description of the entire conception, design, implementation, validation, collection and analysis of results, and operation of the product. The CP book template comprises all the documents presented during the CP seminars and its framework allows the continuation of the project at a more advanced level. Once the CP book is approved by the AG, it is sent to the EE academic staff (the jury) about a month in advance for them to read and comment on. In the CP defense phase of the project, each team presents a 20-minute review of the project to the jury, as it is presented in the CP book. This is the time to ask questions, based on the comments the jury made to get prepared for this last phase.

The seminar course grades are not numerical like most academic courses, but a binary form of "Participated/Not participated". To pass the course, students must have at least 80% attendance, submit the documents approved by their respective AG in the determined time period, and present their progress in the CP in class, as determined in the different faces of the courses. There are penalties for late submission, and these are expressed in the final grade of the CP.

Acquired Skills

During the courses, the students improve skills that were preliminarily acquired in the "Electronic Product Development" course, reviewed in a document at CDIO2022 (Gal, Furman, & Weissman, 2022). The main skills developed in CP Seminar 1 and 2 are "presentation skill" in front of a live audience, "teamwork", "task management" and "time management". Presentation skills are practiced periodically, as students must present some of the milestone materials mentioned in the "Explanation of the CP Seminars' phases" sub-chapter. Also, in a lesson called "Talk like TED", each student is asked to prepare a one-minute speech on any subject and present in front of the class, like an "Elevator Pitch". Teamwork skills have not yet been formally trained, but is well practiced throughout the year, as students must divide the responsibility of the extensive workload among team members in order to manage the completion of the project. Time management and task management skills are naturally enhanced by the course structure, which forces the students to submit documents and develop their project in well-defined time slots. Additional skills, such as independent research, are enhanced by the nature of the project work and research, which contains some innovative areas, in which even the AGs may have limited knowledge. Last but not least are the technical and scientific writing skills, which are practiced to a certain extent. A technical and scientific writing frontal workshop will be added to future courses in the coming years.

Outcomes

This innovative framework of the capstone project process in our EE department has resulted in three notable improvements, compared to the years prior to the change. These improvements are hereby reviewed.

The first improvement refers to an improved level of design, implementation, and integration of hardware-software-mechanics. This results from the positive effect of the seminars, but it is also due to the cumulative effect of three pre-CP courses that were added in recent years: "Arduino Workshop" course, "Raspberry Pie Workshop" course, and "Technology Product Development" course (which was reviewed in a CDIO2022). It is necessary to note that all the components of the CP are developed by the students of the CP team. Two examples of the elevated level of design, implementation and integration of hardware-software-mechanics are shown in Figures 2 and 3.

Figure 2 shows a complex system composed of a photographic camera, connected to a machine learning algorithm based on artificial intelligence (AI) and a mechanical product that acts under the AI trigger, which was placed in the elephant section in the Safari Zoo in Ramat-Gan, Israel. The system uses machine learning algorithms to identify the different elephants in the garden and monitor their social behavior. This behavior is sent by Wi-Fi to a network drive for investigation and follow up. When an elephant touches a virtual button located at the edge of the garden, some fruit is thrown at it as a reward, from a nearby mechanical device.

Figure 3 shows an integrated fall prevention system on a construction site. The system is comprised of a helmet, an In-Site Computing Unit (ISCU) and a mobile application. The helmet alerts the worker to nearby hazards. The ISCUs are placed in potential falling areas and send alerts to all nearby workers. The mobile application concentrates all the data of the site workers in a map of hazards in real-time, used by the administrator of the site.

A second area of improvement concerned the mere fact that all projects adhered to a common timetable and were submitted on time.

Finally, a third improvement referred to a more uniform academic quality of the projects. This is mainly due to the strict milestone schedule, which forced both students and their s to synchronize and submit the respective standardized documentation, as illustrated in Figure 1. In this way, the inherent variation between AG approaches is eased slightly.

a. b.

Figure 2. EleProje – Elephant monitoring system. Figure 2a. System components deployment. Figure 2b. Mechanical fruit reward sub-system.

a. b. c.

Figure 3. NoFall – Construction Site Fall Prevention System. Figure 3a. Helmet and ISCU. Figure 3b. ISCU – In Site Computation Unit. Figure 3c. Mobile app.

Finally, to validate the way students view the modifications made in the CP process, they were polled on several aspects, which included the seminar procedure and contents, and the usefulness of some of the preceding courses. Ten students responded. In general, the response was favorable. Specifically, on the issue of the bi-weekly milestones that they had to adhere to within the framework of the seminars, the mean response (in Likert scale) was 3.9 out of 5. Note that on the negative side, some of the milestones were perceived as somewhat of an overburden.

Despite the extra effort and time required for a course like that, most students think that well-defined milestones and exposure to other student projects help them achieve higher standards. Most of them also perceive the course milestones as beneficial for success in their future work career.

Other responses concerned the importance of the skills practiced in the seminar courses. Here again, the students' view was quite favourable, with respect to the presentation skills (4.3 out of 5), technical writing skills (4.2 out of 5) and independent working capability (4.2 out of 5). Time management and teamwork were favoured to a somewhat lesser extent (3.4 and 3.9 of 5).

DISCUSSION

Our main challenge in managing the CP was to synchronize and equalize the academic process across the various specific projects, time-wise and level-wise. In addition, we intended to enhance the level and complexity of the typical CP. In general terms, the above outcomes indicate that these targets have been achieved by channeling the CP process through the two CP seminars described above.

The students responded favorably, in general. Most of them prefer the seminar format, on working with an AG only. Nonetheless, they noted the increased burden of the need to adhere to the bi-weekly milestones as a disadvantage. In addition, the increased cost, and added course hours may be considered to be somewhat disadvantageous.

It turns out, however, that there is one more aspect that requires attention: raising the level of experiments and validation tests that are carried out on the prototype of the system. There is a need to enrich the experimental part of the CP report, to provide details concerning both the specific functionalities of the system, as well as to quantitatively sketch (using respective graphs) the performance envelope. However, typically, most of the students' energy is invested in building the prototype of the system and demonstrating that it works "reasonably well". There are fewer incentives at the end of the 4th year to carry out meticulous experiments, to cover

the performance envelope. Therefore, it is necessary to direct a special effort to that issue. We started this year by requiring that about a quarter of the CP report be devoted to validation and experimental data. We hope to have some indicative results by the end of the year.
To conclude, CP Seminar 1 and 2 courses have substantially improved the level of CP prototyping and reporting in our EE department and are highly recommended.

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BIOGRAPHICAL INFORMATION

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EXPERIENCES ON THE CREATION OF A MULTI-DISCIPLINARY COURSE IN A METAVERSE ENVIRONMENT

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ABSTRACT

COVID-19 and climate change have both influenced the way we will organize higher education in the future. Turku University of Applied Sciences has developed its own metaverse technology to be used in higher education and industrial competence training. In this paper, we will report how this technology has been adapted to the requirements of higher education in medical sciences and health technology as part of the international Erasmus+ funded Artificial intelligence, innovation & society (AIIS) project which identifies a requirement for immersive multi-user learning. The AIIS project's main objective is to provide a course for medical students and health technology engineering students, where AI, innovation, and soft skills will play a key role, promoting the integration of the course into European universities' curricula. Combining metaverse technology with students from medical and engineering disciplines will allow us to simulate real-life problem-solving very closely while offering participants the unique possibility to deepen their professional understanding and multidisciplinary knowledge. The project´s goals support CDIO's idea on providing integrated learning experiences (standard 7) and active learning (standard 8). This paper outlines our pedagogy considerations based on a sound theoretical framework and how we translated these considerations to suit the constraints and opportunities afforded by a metaverse environment that should be appropriate for both desktop and virtual reality headset users. Moreover, we examine content formatting, course pacing, assessment, and knowledge origin as the key elements of a typical learning landscape and how to adapt these for a metaverse setting. Additionally, to confirm the design choices for content and task presentation in a metaverse, this paper briefly gives the headline results of a large-scale pilot that was run at the time of this writing. Our paper contributes a comprehensive first draft pedagogy model for a metaverse collaborative learning environment, providing a practical contribution for educators venturing into metaverse-based teaching and a theoretical springboard for

researchers to further enhance the body of knowledge concerning contemporary education technologies.

KEYWORDS

Metaverse, Collaborative learning, Virtual learning environment, Artificial Intelligence, Standards: 7, 8

INTRODUCTION

Notwithstanding the influence COVID-19 and global warming have had on how higher education institutions organize their teaching practices, we cannot lose sight of the fact that today's learners are highly digitized members of a knowledge-based society where information lies at a click of the mouse, a stroke of the keyboard, or tap of the finger (Karakas, Manisaligil, & Sarigollu, 2015). However, with an abundance of available knowledge, there comes a real risk for information overload. As such, today's learners are drawn to concise information sources (Newman, 2010) Our learners do not mind rapidly diverting their attention to satisfy their acute curiosities and will easily skip over sources that place unnecessary cognitive strain through, for example, long-winded explanations, tedious context establishment, or elaborate analysis breakdowns (Molyneux, 2018) Turku University of Applied Sciences has developed own metaverse technology to be used in higher education, and industrial competence training. We have defined metaverse to be a combination of social communication, hands-on-training, and real-life integration (Luimula, 2022).

Virtual reality (VR) has both advantages and disadvantages versus a simple 2D graphics or other approaches. For example there is no overall task-workload difference between traditional visualizations and visualizations in VR, but there are differences in the accuracy and depth of insights that users gain (Millais, Jones, & Kelly, 2018). In addition, when analyzing whether and how the delivery mode of an identical video game in either 2D, 3D, or virtual reality (VR) impacts players' game evaluation as well as the brands that are placed in the game, presence was highest in the VR video game and lowest in the 2D video game. The results indicate that 3D and VR lead to higher presence, i.e. to a pronounced feeling of "being in the game", but game evaluation did not differ between the 2D, 3D, and VR version (Roettl J, 2018). Furthermore, previous studies (Banos et al., 2008; Bartsch, Mangold, Viehoff, & Vorderer, 2006; Gorini, Capideville, De Leo, Mantovani, & Riva, 2011; Marín-Morales, Llinares, Guixeres, & Alcañiz, 2020) have suggested that VR can elicit emotions in different visual modes using 2D or 3D headsets. Tian et al. research finds that the emotional stimulus in the stereo vision environment would affect people's perception and presence of the virtual reality environment to a greater extent, which would thereby generate greater emotional arousal (Tian, 2021).

This paper explores the metaverse potential in the context of teaching basic artificial intelligence concepts and soft skills to medical students. This study is done under the banner of the Erasmus+ funded Artificial Intelligence, Innovation and Society (AIIS) project. The AIIS project comprises five European universities (University of Salamanca, Turku University of Applied Sciences, University of Turku, University of Mons, and the University of Thesaly) and three industrial partners (MEUS, SciFy, and GoDataDriven), and a national research network (CIBER).

In preparation for the AIIS project, it was found that medical professionals and researchers alike have identified that basic concepts of data science or machine learning are not covered in medicine curriculums due to the absence of AI professionals involved in medicine faculties. Moreover, medical professionals felt that current education is insufficient in preparing medical students to rapidly adapt to the constant stream of AI development (Wartman & Combs, 2018). Furthermore, the University of Salamanca (USAL) and their respective university hospital professionals also identified a key need to integrate soft skills training into medical curricula. USAL is the coordinating partner of the AIIS project, and Turku University of Applied Sciences (TUAS) is the lead technical partner for creating an online collaborative learning interface, using their own metaverse technology, for medical and health tech students in AI and soft skills.

When it comes to distance (or online) education, there are several key facets that we as educators must consider. Online education has: (a) learners, who; (b) engage with content through; (c) a varied supply of technological solutions to show; (d) their proficiency in a specific area of study (Nam & Jung, 2021) Educators today are targeting learners who expect and demand flexible learning options. We must attempt to provide courses that are not rigid or linear. Courses should offer relevant content tasks (Deloitte, 2018) that learners can do at will and in any order they wish during the period of their program. In addition to flexible learning content, technology and technological innovation is a natural part of our learner's world. Our learners don't mind and even expect, to use innovative devices and interfaces—provided we use them sensibly, consistently and to their learning benefit. The fourth facet of pedagogy that cannot be overlooked is assessment. With online learning, we should leave traditional summative assessments behind. Online courses should look toward new forms of assessment that harness the power of digital breadcrumbs our learners leave behind as they navigate through their courses. In essence, this paper explores how a metaverse-driven pedagogy can meet the anytime, anywhere, and any amount of content today's learners demand (de Reuver, Nikou, & Bouwman, 2016).

To address these contemporary learning habits within the need of the AIIS context, TUAS has created a learning interface that works with their metaverse technology. The AIIS interface is infused with a constructivist pedagogy centered on increased learner autonomy and a sense of competence as the primary learning motivators. The pedagogy was a co-design effort among the consortium university partners and steers toward an anywhere, anytime, and any size learning experience that will suitably engage modern learners.

This paper serves to illustrate how we applied the pedagogy considerations outlined earlier to suit the constraints and opportunities afforded by the TUAS built metaverse technology, in a way that is appropriate for both desktop and virtual reality headset users. Moreover, we examine content formatting, course pacing, assessment, and knowledge origin as the key elements of a typical learning landscape and how to adapt these for a metaverse setting. Additionally, to confirm the design choices for content and task presentation in a metaverse, this paper will briefly report the headline results of a first pilot implementation of the AIIS learning interface.

THE AIIS LEARNING INTERFACE

The AIIS project's main objective is to provide a comprehensive program for medical and health technology students, where AI, innovation, and soft skills play a key role, promoting the integration of the program into European universities' curricula. Using metaverse technology to facilitate collaboration between students from medical and engineering disciplines will allow us to simulate real life problem solving very closely. This in turn offers participants unique possibilities to deepen their professional understanding and multi-disciplinary knowledge. The project´s goals support CDIO approaches on providing integrated learning experiences (standard 7) and active learning (standard 8) (Crawley, 2014).

The AIIS learning program has a theory and a practical component. The practical component makes up a third of the work and is done outside the learning interface with mentors in the form of a machine learning task with real medical data. The theory makes up the remaining two-thirds of the workload and is studied autonomously within the metaverse AIIS learning interface. Students can access all theory material in the learning interface either through regular desktop mode or a VR headset. The theory content is offered to the students in short (maximum 15 minute) videos which are linked to interactive tasks where deeper learning of the topics occurs. There are several different task types that allow various pedagogical learning methods to be used.

The AIIS Learning Program content

The AI and soft skill modules are divided into six topics each. Every topic within the modules has between three and five theory videos coupled to tasks that students must solve. In total, there are 56 theory tasks (26 AI and 30 soft skills) that students must complete.

The AI topics include: (a) Intro to AI; (b) Expert systems and their role in the healthcare sector; (c) Intro to machine learning; (d) Machine learning in the healthcare sector; (e) Intro to machine vision; and (f) Image recognition in the healthcare sector. The AI module intends to provide participants with a high-level understanding of the AI currently prevalent in the healthcare sector. Upon completing the AI module, students will be able to:

- Critically assess the contribution various AI solutions make to their work environments.
- Have meaningful deliberation on AI propositions for the healthcare sector.
- Adapt their working practices to facilitate the integration of AI into their workplace.
- Propose new use cases within the healthcare sector for existing AI techniques.

Although the AI module does not teach the skill for developing and applying relevant AI techniques, some essential knowledge of underlying architecture, applied mathematics and programming algorithmics is introduced. This will give learners the foundational building blocks for a well-rounded understanding of the AI techniques utilized within the healthcare sector.

The soft skills topics include: (a) Self-knowledge and initiative; (b) Capacity to adapt to different situations; (c) Communication; (d) Teamwork; (e) Work organization; and (f) Work ethics. The soft skills module objectives are to make students aware of the importance of soft skills in the employment of their profession. Completing these topics will allow students to develop and put into practice the most valued skills in the sector. In completing this module, students:

- Will become aware of their thought patterns and learn some internal self-regulation mechanisms that allow them greater personal well-being.
- Learn techniques that allow them to better connect with people both verbally and in writing in two-way interactions, in small work groups, and in large audiences.
- Recognize and apply strategies to improve concentration at work, better use of time and organizational planning.
- Will become aware and reflect on medical ethics, especially within the scope of applied artificial intelligence.

As part of the certificate criteria for completing the AIIS theory component, students are required to work on at least 10 of the 56 theory tasks in collaboration with other students.

In addition to the theory topics and tasks, students also work on a specific practice related challenge. There are several challenges to choose from, each one linked to a different subject area. Every student is required to select one challenge. Each challenge requires students to apply their foundational AI knowledge from the AIIS theory component to solving a basic machine learning problem, utilizing a given real-world data set. Every challenge group ideally consists of 10 students and in working together to solve the challenge, under the guidance of a mentor, students are expected to directly apply the soft skills they acquire from the theory in the AIIS learning interface.

A walkthrough of the AIIS Learning Interface

Students who enroll for the AIIS course receive a welcome email that includes a link where they can download the local client as well as a student authentication token that permits them into the learning interface and grants them access to the modules and challenge selection area. Other token types include teachers and visitors, each with their own set of access rights.

Once a student has downloaded the client, installed it, and registered themselves with their token, they can enter the collaborative virtual learning environment (CVLE) where they are represented by an avatar. Students can choose and switch between using a first- or third-person view of the CVLE. Furthermore, students can communicate with other students in the CVLE by means of a push-to-talk mechanic when they are withing close enough proximity of those they wish to talk to.

Upon entering the environment for the first time, students find themselves in a tutorial room where they get to practice the mechanics of accessing and completing a topic task. When students complete (or skip, if they so choose) the tutorial they gain access to the main floor of the CVLE. Figure 1 shows a first- and third-person view of the AIIS CVLE bottom floor.

Figure 1: AIIS virtual learning environment first- and third-person views

The CVLE comprises three floors. The ground floor contains the AI learning material, the next floor has the soft skills material, and the rooftop is where students can select the challenge they wish to participate in. However, the challenge selection rooftop area is inaccessible for the first three weeks of the course. This gives students enough time to build some prior AI knowledge before making a challenge selection.

AI and soft skills knowledge is gained by doing tasks that students can access through tablets from dispensing machines. Each AI and soft skills topic has its own tablet dispenser and these are scattered throughout their respective module floors. That is, the six AI dispensers are on the ground floor and the six soft skills dispensers are on the floor above. Students can do any task from any dispenser at any time. In other words, the virtual learning environment pedagogy does not have a forced linear learning structure. Every topic task has a theory content video lecture with a related accompanying activity.

The only compulsory mechanic students have is that every dispenser has an unlock task students must complete before the rest of the tasks for that specific dispenser become available. Students do not have to successfully complete the unlock task, they must merely submit an effort. Furthermore, the unlock attempt is done without any theory content. The rationale behind this is that students will have an opportunity to self-assess their prior knowledge of a given topic before encountering the rest of that topic's theory content. Once an unlock task is submitted, the rest of the tasks with their respective theory content, as well as the unlock task's theory become available. The unlock task theory now serves as the content to enable students to successfully complete the unlock task.

Figure 2 shows the tablet dispenser for the Intro to AI topic, which has three tasks that students must complete. Students approach the dispenser and select the task they wish to do. The dispenser then releases a tablet students can pick up and move around with freely. The interactive tablet has a theory video for students to watch and an activity to complete that is related to the video content. The AIIS learning content currently contains 11 different activity types, including among others, crossword puzzles, diagram labelling, match the columns, concept mapping, synonym bingo, and more.

Figure 2: Tablet dispenser and tablet for the Intro to AI topic

Every task (theory + activity) has a certain number of micro-credentials attached to it, based on how long a task is expected to take to complete. In the AIIS CVLE, one micro-credential is equivalent to approximately 30 minutes of work. To complete the CVLE theory material (i.e., not including the practical challenge), a student must collect 102 micro-credentials from the 56 available tasks. Students can repeat a tasks as often as they like until a successful submission is made that earns the set micro-credentials for that specific task.

Students can track their micro-credential progress by means of a dashboard that is pervasively available while they are active in the CVLE. The dashboard contains a general view (Figure 3) that provides summary information about the learning progress on a per-module level, as well as detailed views for the AI (figure 4) and soft skills modules that present the student's progress on a per-task level. The dashboard also contains explanatory videos to guide students with the mechanics of the AIIS CVLE, as well as introductory videos for each module.

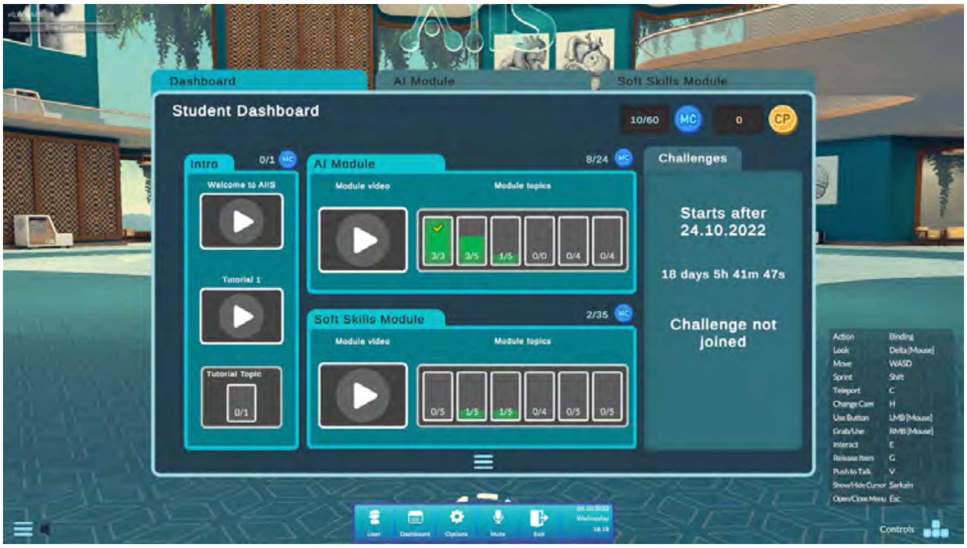

Figure 3: General view from the student dashboard

Figure 4: Detailed AI module view from the student dashboard

In addition to completing 102 micro-credentials, students must also collect at least 10 collaborator points. Students gain one collaborator point when they join a task initiated by another student. When a task is initiated, other students in the CVLE will see an indicator pole that a task has been started in that specific location with information on how many collaborator seats are available for that task. There are two collaborator seats available when a task is initiated (i.e., when the initiating student starts to interact with a task tablet). If a student wishes to collaborate, they enter the task area (indicated by a dashed circular line in the CVLE) and select the option to collaborate. Communication between the collaborators and task initiator continues with the same push-to-talk mechanic as in the rest of the CVLE, but only those within the collaborator circle can hear this conversation. The collaborator point is granted to the collaborator if they are in collaboration mode when the initiating student submits a correct solution to the task. If students exit the collaboration before the submission, they do not gain a collaborator point. Students cannot get multiple collaborator points for the same task. Only the student who initiates the task will gain micro-credentials for that task and does not gain any collaborator points, irrespective of whether there were collaborators.

The AIIS CVLE also contains reflection zones that appear next to the task dispenser of a topic for which the student has successfully completed all tasks. The reflection zones are typically a poster with additional information, latest developments, or some newsworthy content regarding the completed topic. Students are not expected to perform any activities in these reflection zones—they serve purely as points of interest for students to read and reflect on.

FIRST ITERATION PILOT PHASE

At the time of writing this paper, the AIIS collaborative virtual learning environment was piloted among 115 medical students from four of the partner universities and 10 health technology engineering students from Turku University of Applied Sciences. The engineering students were evenly divided among the challenges so that there was at least one technically experienced person in each of the challenges to ensure a smooth setup and utilisation of the architecture required to complete the machine learning challenge tasks. The engineering students also completed the CVLE theory material.

Of the 125 students who started the pilot, 96 received certificates for completing the course (a completion rate of roughly 77%). We conducted a usability and user experience survey with those who enrolled for the course and the consensus was that the AIIS collaborative virtual learning environment was an overall positive experience. A detailed analysis of the pilot and user experience survey will be published once their respective data sets have been fully analysed.

DISCUSSION

The aim of this paper was to describe the outlines of our pedagogy considerations based on a sound theoretical framework and how we translated these considerations to suit the constraints and opportunities afforded by a metaverse environment. We also examined content formatting, course pacing, assessment, and knowledge origin as the key elements of a typical learning landscape and how to adapt these for a metaverse setting. Moreover, we showed that a collaborative learning environment can be more than a simultaneous user experience. With the AIIS collaborative virtual learning environment pilot, we showed how an interdisciplinary student cohort (medical and engineering) can meaningfully collaborate to successfully complete a diversified subject set (AI and soft skills) in a virtual environment underpinned by metaverse technology.

Our paper contributes a first draft pedagogy model for a metaverse-driven virtual learning environment. This provides a practical contribution for educators venturing into metaverse-based teaching and a theoretical springboard for researchers to further enhance the body of knowledge concerning contemporary education technologies, both in general terms and more specifically under the CDIO framework. The work we presented in this paper particularly embraces CDIO standards 7 and 8. The fundamental cooperation opportunity the TUAS metaverse technology grants and the AIIS CVLE requirement for students to collect collaborator points across two distinctly different subject groups (AI and soft skills), clearly shows an integrated learning experience with a pedagogical approach that fosters the learning of disciplinary knowledge simultaneously with personal and interpersonal skills (CDIO Standard 7) (Brodeur & Crawley, 2009). The practical and continuously engaging nature of the non-linear AIIS learning experience squarely addresses the CDIO framework standard 8, whereby it is stated that active learning methods should engage students directly in thinking and problem-solving activities. Not just are the AIIS metaverse-driven theory tasks practically engaging in their own rights, but they encourage reflection, group discussion, and direct application in the practical challenge component of the AIIS learning program.

CONCLUSION

Implementing the CDIO model to metaverse technology allows for novel ways to educate. Student communication and collaboration are now possible on a level that cannot be achieved using present learning platforms. This more natural interaction enables immersive and deeper collaborative learning experiences across subjects by multiple study disciplines. In summary, virtual reality can provide added value compared to a simple 2D environment through increased immersion, spatial understanding, interactivity, presence, empathy, realism, visualization, and novel experiences. These benefits make VR an increasingly popular technology for a wide range of applications across different education domains.

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A DESIGN-IMPLEMENT EXPERIENCE WITHIN COMPUTER VISION

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ABSTRACT

A design-implement experience in computer vision, which is part of the Bachelor’s program in Artificial Intelligence at the Federal University of Goiás, Brazil, is presented. The program runs over four years, and the design-implement experience is part of a course module in computer vision in the third year. The first years of the program contains mandatory course modules in mathematics, computer science and entrepreneurship, and the module in computer vision is the first module where students were introduced to work in projects in the CDIO form. As a result, some of the students which had previous knowledge about project management and development performed well and achieved solid results. Some other students which underestimated the project scope had a less solid performance and achieved weaker results. However, the final overall feedback from the students was positive and lessons learned were appointed for future improvements.

KEYWORDS

Design-implement experience, computer vision, project-based learning, Standards: 2, 4, 5, 11

INTRODUCTION

In recent years, universities and research institutions all over the world have showed increasing interest in the assessment and improvement of the quality of higher education. The CDIO initiative is one of the efforts that have received the most attention all over the world, as demonstrated by the amount and quality of the universities that have subscribed to it, to name a few, MIT in the US, and KTH in Sweden. The impact of the CDIO initiative has more recently been extended further to universities in Brazil. More specifically, the Federal University of Goiás (UFG) has recently implemented with a CDIO design-implement experience in one of their programs. The effort was made possible due to a close bilateral collaboration between scholars from Sweden (Linkoping University) and Brazil (Federal University of Goiás).
The purpose of this work is to present the results of the implementation of a CDIO design-implement experience in computer vision within the Bachelor’s program in Artificial Intelligence at the Federal University of Goiás. The CDIO experience was implemented and completed on a full semester during 2022 and 2023, and it is the first experience on its class to be performed

at UFG. Numerous examples of design-implement experiences have been reported within the CDIO community, and one example is reported in Svensson and Gunnarsson (2012). Also, the CDIO Knowledge library, that is reached via the CDIO web site, contains many examples of such learning activities. Even though the examples of design-implement experiences cover a wide range of disciplines there are very few published examples within the CDIO community related to the computer vision field. Areas somewhat related to computer vision are treated in, for example, Bermejo et.al (2016) and Var Torre and Verhaevert (2017). Hence, to the best of the authors' knowledge no works have been reported within the CDIO community related to computer vision and, thus, the novelty of our contribution. Even though it has not been reported in the literature, the course Images and Graphics Project Course CDIO (2023), given at Linköping University, is an excellent example of a course within computer vision designed according to the CDIO framework.

BACKGROUND INFORMATION

The CDIO framework

The fundamental aim of the CDIO framework is to educate students who are "ready to engineer" and to raise the quality of engineering programs, see Crawley et al. (2014) and the web site CDIO Initiative (2023). The framework relies on four key components:

- A "definition" of the role of an engineer.
- Clearly defined and documented goals for the desired knowledge and skills of an engineer listed in the document CDIO Syllabus (2023), which serves as a specification of learning outcomes.
- Clearly defined and documented goals for the properties of the engineering education program collected in the document CDIO Standards (2021), which works as guidelines of how to design a well-functioning engineering education.
- Methods and tools for systematic development and management of education programs.

According to the CDIO framework, see Crawley et. al. (2014) page 50, the goal of engineering education is that every graduating engineer should be able to *Conceive-Design-Implement-Operate complex value-added engineering products, processes, and systems in a modern, team-based environment.* This formulation can serve as a definition providing the basis for the entire CDIO framework. Adopting the definition, it is natural to design and run an engineering education program with this in focus. The CDIO Syllabus is a list of the desired knowledge and skills of a graduated engineer. The document can be found via the CDIO web site, and it consists of the following four main sections:

1. Disciplinary knowledge and reasoning
2. Personal and professional skills and attributes
3. Interpersonal skills: Teamwork and communication
4. Conceiving, designing, implementing, and operating systems in the enterprise, societal, and environmental context – The innovation process.

Via the sub-sections and sub-sub-sections, the document offers an extensive list of knowledge and skills, which can be used to specify learning outcomes of individual courses or education programs. The CDIO Standards (2023), which also can be found and explained in detail via the CDIO web site, is a set of twelve components that are necessary for designing and running an engineering program that enables the students to reach the desired knowledge and skills.
The CDIO framework offers a variety of tools for development and management of education programs, including for example the so-called Black-box exercise and the CDIO Syllabus survey. These tools are described in some detail in Crawley et al (2014).

CDIO in Brazil

The CDIO framework has received considerable attention in Brazil, and several universities have joined the CDIO Initiative. Also, several papers describing the implementation of the CDIO framework in the Brazilian context have been published. See, for example, Lourenco and Veraldo (2015), Neto et al (2019), Passos et al (2019), and Rezende et al (2022). As pointed out in Rezende et al (2022) the CDIO framework is very valuable in the process of implementing the new national guidelines for engineering education.

THE CONTEXT OF THE DESIGN-IMPLEMENT EXPERIENCE

The Federal University of Goiás

The Federal University of Goiás (UFG) is a public research institution located in Goiania, state of Goiás, Brazil. It is the largest university in the Central-West region in Brazil, immersed in a socioeconomical environment characterized by a strong agro-industrial ecosystem. With 59 years of history, UFG has 104 undergraduate schools, 78 post-graduate programs, with approximate 22,000 students distributed across four campuses. The Bachelor's program in Artificial Intelligence, where the module in computer vision belongs to, is run by the Institute of Informatics at UFG, in addition to the three other Bachelor's programs Computer Science, Software Engineering, and Information Systems.

The Bachelor's Program in Artificial Intelligence

The Bachelor's program in Artificial Intelligence, commonly shortened as BIA from its acronym "*Bacharelado em Inteligência Artificial*" in Portuguese, is the first program of its class in Brazil and the newest undergraduate program offered by the Institute of Informatics at UFG. The program begun activities in 2020 with the purpose of fulfilling the lack of professionals in artificial intelligence in the local Brazilian market. The admission system of BIA allows 40 new students each year, with an entrance examination at the beginning of every year. The BIA program has currently three ongoing classes and an expected date of graduation for the oldest class by the end of 2023. BIA is a four-year program, composed of eight semesters and 3,200 hours of credits in total. The first two years include course modules on mathematics, computer science and entrepreneurship. The last two years contemplate introductory, intermediate, and advanced courses on machine learning, deep learning and their applications in natural language processing, reinforcement learning and robotics, finishing with a pre-professional internship on the last semester at the Center of Excellence in Artificial Intelligence – CEIA (2023) as a part of the requirements for graduation. The computer vision module runs on the fifth semester. It has 64 hours of credits in total and it is the first course of BIA where a CDIO design-implement experience is introduced.

THE DESIGN-IMPLEMENT EXPERIENCE IN COMPUTER VISION

Structure of the course module and learning goals

The computer vision module runs over 16 weeks and corresponds to approximately 3 ECTS credits (60 ECTS credits correspond to one year of full-time studies), which means the students are expected to spend 64 hours on the module.

The learning outcomes contained goals related to (unsupervised) description of a computer vision solution, (supervised) step-by-step implementation of a computer vision algorithm, and the (following-instructions) design of a computer vision system. Here the expressions unsupervised, supervised, and following-instructions refer to the three levels of independence of a student towards reaching the goals specified in the course's Study Plan.

In the first eleven weeks of the module the students receive lectures involving theoretical and practical aspects of computer vision. During these weeks, the students are evaluated on the unsupervised and supervised learning outcomes. The practical activities are designed to be performed in teams and such teams are previously defined on the first week of the course.

The last five weeks of the module are dedicated to the development of the CDIO design-implement experience. The following-instructions learning goal is covered on this step. Five projects are suggested to the students considering applied computer vision tasks, such as 3D-reconstruction, visual odometry and object detection. The teams receive instructions related to the details of the deliverables and their outcomes a week in advance. The project concludes with a written report, an oral presentation and the discussion of the lessons learned from the execution of the project.

Work process and assessment

Twenty-five students took part in the course. They were divided into five teams, with five students in each team. The students were free to choose who to work with and each team had a leader in charge of handling the general team management and communication with the instructor. The tasks were formulated to be developed in five weeks including three incremental work submissions through the GitHub's versioning system. The design-implement experience is evaluated progressively along each submission. The final assessment is done via a written technical report, an oral presentation, and a discussion of the results. Each team have access to some amount of support and supervision during the project's lifecycle. At the end, three teams are randomly selected to participate in a focus group to collect oral feedback from the students about the realization of the design-built experience. The meetings are conducted individually with each group with the aim to reduce cross-feedback biases. The feedback is collected from the leader of each group, who is in charge of collecting the group's feedback previous to the encounter.

Examples of project tasks and results

The teams were attributed five projects of similar workload, including 3D reconstruction, object detection, classification of falls, visual odometry and hand-gesture recognition. Some important observations were identified at the completion of the projects regarding the level of the outcome achieved. The teams who had higher maturity and previous experiences in project development were able to reach the project goals to the point of including additional features and project extensions.

A first team, involved in the fall detection task, chose such topic because it was part of a capstone project they were developing in parallel. Due to this, the participants had already some amount of intimacy with the topic and experience with the type of results they should expect, as they run preliminary tests in advance. With this in consideration, the definition of project tasks and scope were clearer from the kickoff and the team's effort was put on outreaching the original project outcomes by using the capstone project as a benchmark to improve the accuracy of the fall detection task.

A second team, which worked with the hand gesture recognition project, chose such topic because parts of the members were already involved in a robotics challenge of similar scope that was led by Pequi Mecânico, the Robotics group at UFG (2023). In such a case, the team's effort was put on leveraging the team's knowledge in more advanced tasks demanded by the former challenge, such as objection detection and recognition of visual features from the hand. The project tasks and outcome were only well understood by part of students who were already involved in the robotics challenge. This resulted in a heterogenous knowledge about the project goals between the team members and, thus, the learning outcomes achieved individually were diverse as well. The team started with a good performance and motivation, but soon found insufficient time and internal support from the members with less confidence about the topic to be able to surpass the hardest tasks. As a result, part of the team members showed an excellent performance during the oral discussion, whilst some others showed just fair or weak contributions.

A third team, which developed the 3-D reconstruction task, underestimated the scope of the activities. This was mainly due to an excess of confidence about the task, which they considered to be sufficiently easy a priori. As a result, the team was able to technically describe the methodology towards solving a reconstruction task but was unable to complete it due to foundational difficulties found during the implementation, such as implementing a successful outlier rejection strategy, and other more advanced steps.

In summary, the performance of the designed-implement experience of the computer vision class was satisfactory and diverse. The level of performance of the students much depended on hard skills already incorporated by the team members, such as the level of technical expertise about the topic, but also depended on soft skills, such as good project management abilities. This is a result that can be improved on a next run of the course module, for instance, by showing the results from previous CDIO projects to the next classes from the beginning of activities, and by using the practical hours worked at the first weeks of the module to strengthen the hard and soft skills required to achieve a successful design-build experience.

Observations and student feedback

Some interesting observations and lessons learned can be summarized after the learning activity:

- The amount of proper weekly follow-up from the instructor was restricted, mainly because of limited resources in terms of availability of teaching assistants for extra class support.
- Another observation was that teams that were more cohesive also achieved more mature results. Such teams applied a key strategy, which was establishing connections with other related projects they were conducting in parallel. When the level of understanding of the topic was homogeneous, the results were more profound, otherwise, mixed results were achieved when only part of the team members showed a proper understanding of the project tasks they were involved with.
- A third observation was the difference in the level of maturity achieved by the teams at the completion of each project. Some of the teams underestimated the challenges they were given. Therefore, the successful performance of the steps to solve the problem was harder than they expected. This led to a progressive lack of motivation and, therefore, weak results at the end. On the contrary, teams that had some previous knowledge about the topic made a clearer identification of the challenges to be solved and were able to successfully complete the experience on time.

Despite the difference in the performance of the teams, the overall feedback from the students was positive. According to the students, the highlights from the design-implement experience included:

1. Validating the theory in practice.
2. The opportunity to run a computer vision project according to their own interests.

The conclusion from the students was that the CDIO design-implement experience helped them not only to increase their technical level of maturity, which is a pre-requisite of the course module in computer vision, but also to put project management skills in practice, such as schedule planning, a weekly assessment of activities, and the capacity to operate with a limited budget of time and resources.

CONCLUSIONS

In this work we described a CDIO design-implement experience within computer vision at the Bachelor's program in Artificial Intelligence, Federal University of Goiás, Brazil. The results showed that students appreciated the CDIO experience from a professional perspective, highlighting that it helped them to incorporate both the technical maturity required to execute advanced engineering tasks and the project management skills required to succeed on completing the project tasks. In the future, the design-implement experience could be improved with a threefold strategy. Firstly, by showcasing the results from previous classes to newcomers. Secondly, by implementing a teaching assistant support. Thirdly, by extending the CDIO framework to other course modules within the Bachelor's Program in Artificial Intelligence to be able to share and learn from the experiences of other CDIO instructors.

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ONLINE COURSES FOR TEACHING ENGINEERING PROFESSIONALISM

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ABSTRACT

In today's team-based and distributed workplaces, engineers who work together to solve complex technical challenges require technical competencies but also require other engineering professional skills, e.g., the ability to work in multidisciplinary teams, the ability to deal with social issues, and self-awareness. Therefore, engineering educational programs need to prepare students for the demands of their future workplaces. The COVID-19 pandemic required changes in education, one of which was to switch to a distance-learning mode. Teaching professional skills for engineering students was already challenging, and it became even harder during the COVID-19 pandemic with the demand for distance-based learning through online courses. Transitioning to an online delivery format typically requires substantial re-tooling of traditional courses. Our study is based on converting an eight-week on-campus professional skills course, where the physical meeting had been a central component of the pedagogy, to an online course during the COVID-19 pandemic. Four professional skill topics were taught in the course. 74 students signed up for the course and 87% completed the course. In the paper we discuss both positive and potentially problematic aspects of online courses for teaching professional skills in engineering education.

KEYWORDS

Computer science education, software engineering, electrical engineering, personal management, social competence, communication, teamwork, engineering profession, CDIO Standard 2.

INTRODUCTION

Today's engineers need both technical competencies and professional skills when working together to solve complex technical challenges. The purpose of this paper is to investigate how online courses can be designed to teach professional skills using a reflective practice (Idrus, Abdullah, et al., 2009) and experiential learning with the key components of learning-by-doing (Kolb, 1984). These skills are included in the CDIO standard 2: learning outcomes for personal and interpersonal skills (Crawley, Malmqvist, Ostlund, Brodeur, & Edstrom, 2007; Malmqvist, Edström, & Rosén, 2020).

Engineering professionalism

The term *professional skills* (commonly called “soft skills”) describes non-technical skills and human-focused competencies essential for the engineering profession (Berdanier, 2022) such as the ability to work in multidisciplinary teams, conflict management, communication, social justice, equity, leadership, and ethical reasoning (Itani & Srour, 2016; Matturro, Raschetti, & Fontán, 2019; Sahudin, 2022; Stevenson & Starkweather, 2010). The six critical core competences that are indicative of characteristics important to successful IT project management are: leadership, the ability to communicate at multiple levels, verbal skills, written skills, attitude, and the ability to deal with ambiguity and change (Stevenson & Starkweather, 2010). A literature review identifying factors influencing the employability of engineering graduates shows that the primary factors are professional skills, problem solving skills, functional (knowledge) skills, and academic reputation (Sahudin, 2022). Furthermore, six groups of professional skills that are of importance for engineers are: critical thinking, creative thinking, communication, teamwork, ethical perspective and emotional intelligence (de Campos, Resende, Fagundes, et al., 2020). Technological development and accelerated globalization has led to increased demands in engineers’ professional skills with regard to communication, teamwork, and management skills (Itani & Srour, 2016). The COVID-19 pandemic required radical changes in society and the importance of professional skills in workplaces has become even more important after the COVID-19 pandemic for today’s team-based and distributed workplaces (Malik & Ahmad, 2020). Therefore, educational programs in engineering need to prepare students for the demands of the workplace. In addition, focusing on professional skills even helps students in their studies since these skills have an impact on the students’ performance in classes and academia (Berdanier, 2022). Professional skills can be developed and increased through education and training (Kyllonen, 2013). Therefore, university programs should focus on learning outcomes linked to professional skills (Finch, Hamilton, Baldwin, & Zehner, 2013) and courses focused on the learning of relevant professional skills for the engineering profession need to be integrated into the engineering curriculum (Jelonek, Nitkiewicz, & Koomsap, 2020). However, it is common for there to be a significant gap between the professional skills required by industry and the skills acquired by engineering graduates such as communication and systematic work planning (Gope & Gope, 2022).

Learning in Online Courses

Teaching professional skills to engineering students has many challenges, such as teaching classes with large numbers of students, limited time to cover the syllabus, and students’ negative attitudes towards professional skills in the classroom (e.g., skipping lessons incorporating professional skills and students not being interested in developing their own professional skills) (Idrus et al., 2009). Students’ attitudes about the importance of these skills is another challenge. Using the term “professional skills” instead of the more common term “soft skills” emphasizes the importance of these skills for the engineering profession (Berdanier, 2022). The COVID-19 pandemic also required changes in education, one of which was to switch from face-to-face to online learning, which has been challenging in many ways (Heng & Sol, 2021). Teaching professional skills to engineering students is challenging, and it became even harder during the COVID-19 pandemic due to the demands of distance-based learning through online courses (Atolagbe & Yan, 2022; Idrus et al., 2009; Malik & Ahmad, 2020), where the learning process is mediated by technology via the internet. Therefore, course designs need to be adapted for online teaching. Students achieve better learning results in online courses if they are properly guided by tutors

(Vlachopoulos & Makri, 2019; Zacharis et al., 2009) and direct guidance to access resources make students engage with the materials (Murray, Pérez, Geist, & Hedrick, 2012). Learning outcomes in online courses can be improved by increasing flexibility and learner autonomy, and through extensive use of digital technologies (Vlachopoulos & Makri, 2019). Active learning and incorporation of meaningful and multiple ways of interacting with students is very essential for the student engagement in online courses (Dixson, 2010). There are three important types of student interaction in online courses: student interaction with online content, student interaction with remote teachers, and student interaction with distant student peers (Abouhashem et al., 2021; Bernard et al., 2009; Luo, Zhang, & Qi, 2017). Teachers should build strong connections with their students via, e.g., frequent technology-facilitated dialogue and moderated student discussions (Huss, Sela, & Eastep, 2015). Constructive feedback, providing students with clear guidelines, and addressing reflective questions strengthens student engagement (Aderibigbe, 2020). Student interaction with the teacher is a critical factor for enhancing social interaction among peers in online courses (Cho & Tobias, 2016). When students think, reflect, engage, and learn collaboratively with other students in online courses they will be engaged (Aderibigbe, 2020).

Learning through reflection

Formal teaching, learning activities, and support programs are usually used to develop professional skills (Atolagbe & Yan, 2022). Reflection is an important way of learning (Daudelin, 1996) and formal reflective practices can encourage learning (Idrus et al., 2009). For example, spending one hour reflecting on a challenging situation (by, for example, using questions and guidelines, either alone or with another person) can significantly increase learning from that situation (Idrus et al., 2009). Kolb's Experiential Learning Theory explains the key components of learning-by-doing (Kolb, 1984). According to the theory, effective learning has four stages: (1) having a concrete experience followed by (2) reflective observation (the learner observes and reflects on the new experience based on their existing knowledge) which leads to (3) abstract conceptualization (the learner forms abstract concepts) which are then (4) used in future situations (active experimentation) when the learner applies the concepts to see what happens, resulting in new experiences. By creating a reflection practice, knowledge can be gained through dialog with others. The dialog seminar method has been shown to contribute to the development of professional skills for young (Backlund & Sjunnesson, 2012) as well as experienced engineers in industry (Backlund & Sjunnesson, 2006). The method's main purposes are: (1) establishing a common language among participants, (2) developing reflective and analogical thinking, and (3) developing experience-based knowledge (Göranzon & Hammarén, 2006). Individual reflection is gained by writing a reflection essay, which is then followed by group reflection via discussions with others in dialog seminars. This requires the participants to reflect and articulate their reflections in text, which can be challenging for students who may need tools to reflect in a structured way. The Gibbs reflection model is one of the most famous cyclical models of reflection giving structure to learning from experiences through six stages of exploring an experience: description, feelings/thoughts/reactions, evaluation, analysis, conclusion, and action plan (Gibbs, 1988). The Gibbs model has been used to reflect on professional skills for engineers (Berglund, 2018; Berglund & Heintz, 2014).

THE ONLINE ENGINEERING PROFESSIONAL SKILLS COURSE

An established on-campus professional skills course in two bachelor engineering programs (Berglund, 2018) was converted to an online course. The course in length is eight weeks and gives 2 ECTS credits. Four professional skill topics are taught in the course: personal leadership, communication, teamwork, and the engineering professions. The essentials of the course are a) *reflective practices*, wherein learning is gained by reflection, individually through written essays and together with others through discussions with other students in obligatory scheduled online dialog seminars, b) *experience development*, which is using obligatory assignments followed by the individual and group reflections. The learning objectives of the course are that after completing the course a student should be able to: (1) plan, prioritize, and perform their own work within the stipulated time, (2) reflect on their own skills and approaches, (3) reflect on what leads to effective teamwork and personal effort in interaction with others, (4) reflect on the education and their own learning, and (5) communicate with others in other roles as a colleague.

The Course Structure

The course contains four modules, and each module starts with a lecture that introduces the topic of the module. The dialog seminar method (Göranzon & Hammarén, 2006) is applied in the course and three online 3-hours dialog seminars are scheduled in the course. Before the seminar students do some preparatory work, including: (1) obligatory assignments that give the students experiences in the topic, (2) appropriate reading materials and/or online talks that stimulate individual reflection, and (3) writing an obligatory individual reflection essay in 1-2 A4 pages based on their experiences on the topic using the Gibbs reflection model (Gibbs, 1988) (enabling individual reflection, see Figure 1). All assignments must be handled in advance according to the course schedule using the university tool. The reflection essay is the entrance ticket to the online dialog seminar and no essay means no participation. Table 1 presents a summary of all activities in the course and the technology used for each activity.

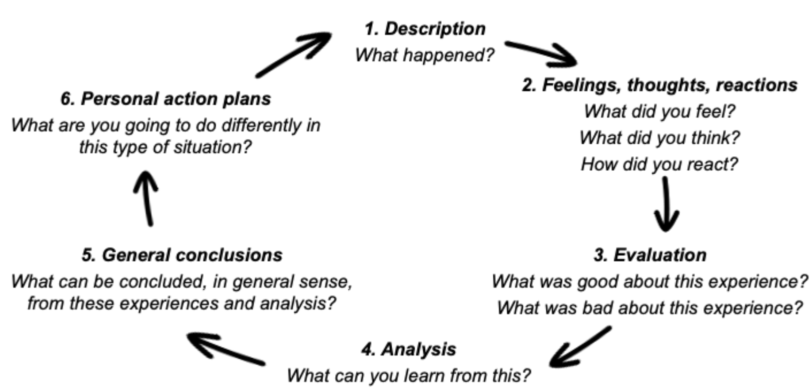

Figure 1. The Gibbs reflection model used when writing the reflection essay.

The students are divided into groups with about 8 students/group and each group is tutored by a seminar leader called a mentor. The mentors in the course are master students from two engineering programs in computer science who have taken an advanced professional skills course with 6 ECTS credits (Berglund, 2018; Berglund & Heintz, 2014). When a group meets in an online dialog seminar each student in the group has about 15 minutes. The first student

Table 1. The structure of the course

Goal	Activities	Online learning technology
Topic introduction	Lecture and workshop	Communication platform - Zoom
Knowledge gain	Study materials	Course web page
Experience gain	Obligatory assignments	University tool 1
Individual reflection	Obligatory reflection essay	University tool 1
Group reflection	Obligatory dialog seminar	Communication platform - Zoom
Student progress	Result reporting	University tool 2, result reporting
Information distribution	Written communication	E-mails

starts by reading out loud his/her own reflection essay (the possibility for individual reflection) and then the group discusses the reflection essay - asking questions and sharing their own experiences, which leads to group reflection and experience exchange. When the time is up it is the next student's turn. The mentor's tasks during the seminar are to make sure that students participate in the dialog, that discussions are focused on the relevant topic, and to keep track of time. All activities in the course are carried out online and the communication tool Zoom is used during interactive in-class activities. During the dialog seminars students are required to use video cameras so all the participants can see each other during the discussions to capture both verbal communication and non-verbal cues. The grades students can get in the course are *pass* or *fail*. In order to pass the students have to pass all the obligatory assignments and reflection essays. They have also to participate actively in all three obligatory dialog seminars.

The Course Modules

The course starts with an introductory lecture that introduces the course goals and outline. The course has the following four modules, see Figure 2:

1. *Personal management* focuses on planning, prioritization, and monitoring of one's own tasks as well as working with long- and short-term planning. The students have three mandatory assignments before writing the reflection essay: (1) A diary assignment: write a diary for 1 week capturing own activities (to increase self-awareness). (2) Self-analysis: analyze the captured data in the diary (to stimulate reflection about own personal management). (3) Planning: plan the rest of the semester (to practice long-term planning) and make a detailed plan for a week (to practice weekly and ”day by day” planning) based on the insights from the diary and self-analysis.

2. *Communication* includes effective communication (Guo & Sanchez, 2005), active listening (Robertson, 2005; Tyagi, 2013), and giving as well as receiving feedback using the experience cube (Bushe, 2011). Two mandatory assignments are included in this module and need to be done before writing the reflection essay: (1) Providing feedback: each student must give constructive feedback to four different people. Two people receive positive feedback, and two people receive criticism. The feedback has to be formulated using the experience cube (Bushe, 2011) and a tool for receiving feedback (the feedback stair) is used to understand the reactions of the receiver of the feedback. (2) Practicing effective communication: for at least one week, each student must use at least one tool that makes communication more effective.

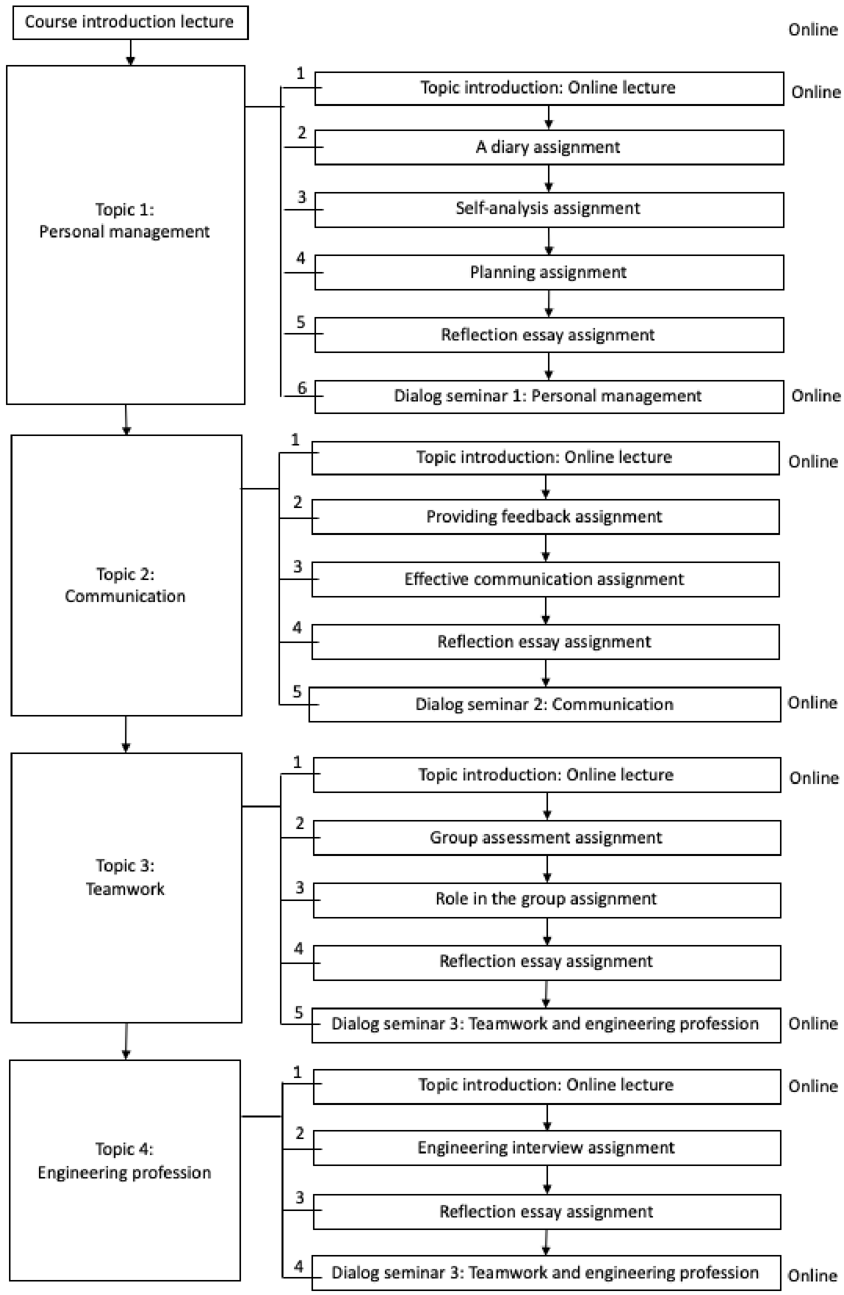

Figure 2. The course modules

3. *Teamwork* containes effective teamwork (Wheelan, 1994), personal effort in interaction with others, and different social phenomena that occur in teams such as social loafing (Liden, Wayne, Jaworski, & Bennett, 2004) and groupthink (Janis, 2008). The development of a group taught in the course is based on Susan Wheelan's Integrated Model of Group Development (IMGD) (Wheelan, 1994). Two mandatory assignments are included in this module and must be done before writing the reflection essay: (1) Group assessment: Each student identifies two work groups (one dysfunctional and one functional) that s/he works for or has worked in and with others. Then, they assess the stage the groups are/were at according to the IMGD model (2) Roles in the group: Identify the different

roles the group members had.

4. *Engineering profession* gives students a better understanding of what they are going to work with in the future. A mandatory interview assignment is included in this module and needs to be done before writing the reflection essay to help students get insights into real life, practice listening, and to develop their professional network. Each student interviews an engineer, who is not a friend or relative, and asks questions about their daily work and career.

COURSE EVALUATION

74 students signed up for the course in the year 2021 and 64 completed the course (87%). The course was evaluated with four surveys: one survey after each dialog seminar (about the topic and related assignments and seminars) and a final survey (about the whole course). Surveys 1-3 were created by the course examiner and sent to the students at the end of each seminar, while the survey 4 was created by the faculty and sent to the students by the central course evaluation system by e-mail after course completion. The response frequency was higher for surveys 1-3 (survey 1: 66 answers, 89.19%; surveys 2 and 3: 61 answers, 82,43%) and lower for survey 4 (19 answers, 25,68%). The results from the evaluations are presented below.

1. The course structure supports students' learning - According to survey 4 the students think that the pedagogical implementation of the course has been supportive of their learning (average score 3.21 on a scale from 1=not at all to 5=absolutely, standard deviation = 1.4). Most of the students find that the course is relevant to their education (average 3.89, standard deviation = 1.29). Looking at the students' comments about the course we see that the students who appreciate the course can see its relevance to the engineering profession as well as their own personal development, such as this comment:

> *"Important course for engineers. Fun course for personal development. Important topics to talk about and reflect on."*

The average overall grade the students give the course is 3.47 (standard deviation 1.26) in survey 4 and 3.48 in survey 3 (standard deviation 1.01). Looking at the comments from survey 3 we see that some of the students were skeptical about the course before they started the course and then changed their opinions as the course progressed, e.g.:

> *"A VERY good course. I did not think I would like it before I started, it felt fuzzy at first. But after the first dialog seminar, I really started to like it and appreciate how important it was to prepare one as an engineer after graduation."*

Students appreciated the content of the course and understood the importance of learning the topics highlighted in the course. Students felt that the course prepared them for their future professions, gave them an understanding of the engineering profession, and helped them to develop personally. Some students had positive attitudes towards the fact that the course was given online. However, some students thought that the dialogue seminar was rewarding, but that it did not feel natural to have it in Zoom. One of the challenges with having seminars in Zoom was that many students talked at the same time.

"Even though everything has been remote, it has worked very well. I thought it was very rewarding to write a diary like we did during the first assignment."
"Seminars in group worked very well in remote mode."

2. Course modules are rewarding - In the third survey at the end of the course the students were asked to choose the most rewarding modules of the course, see Figure 3. Students highlighted the following regarding the question about what they had learned from the assignments and seminars in each module.

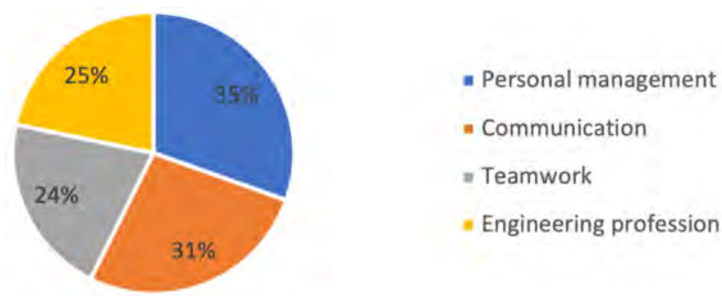

Figure 3. Most rewarding parts of the course

- **Self-insights gained from the personal management assignments:** Students got an understanding of their behavior and study situations regarding how they used their time, how they did things, how they didn't do the things they said they would, how little they studied, how much they played video/online games, and how much they used their mobile phones. The understanding led to self-insights such as better usage of time, doing the things they intended to, and that mobile usage should be reduced. One student wrote the following comment:

    "The task allowed me to take a step back and see myself in the mirror. Analyze how I feel today, what I do, how my studies are going. I have got a slightly changed picture of myself. And knowledge of something is the first step to being able to do something about it, improve it, understand it."

- **Learning about how to be more effective:** Some students mentioned that they got ideas on how to be more effective by doing the assignments and discussing them with other students. Students learned that there are several ways to plan and structure and that it is important to find what works best for yourself. One student wrote the following comment:

    "DIVIDE THINGS INTO SMALL GOALS. God what an effective tool!".

- **Learning about study techniques:** Students learned study techniques and studying effectively by, e.g., taking micro breaks while studying and using an app to lock the mobile phone and not be distracted while studying.

- **Learning about mental and physical health:** Students gained an understanding about how health affects one during the day in general and one's studies specifically. They came to know more about the impact and importance of mental health on one's studies, understood the impact of physical health, and said they would try to get more exercise.

- **The importance of giving well formulated positive feedback and criticism:** many students highlighted that it is difficult to give feedback in general and criticism specifically. However, they understood the importance of feedback and that they could become better at it by training. Furthermore, they came to understand that there are good and bad ways to give feedback and that it is important to be open to feedback.

- **Receiving feedback:** students commented that they learned about how people react when they receive feedback, and how to think about or manage one's own emotions and the emotions of others when receiving feedback. One student had the following comment:

  > *"One's reaction to particularly positive feedback often plays a big role in how the person who gave the feedback will communicate with one in the future."*

- **Effective communication and active listening:** Students noted the importance of how a person formulates what s/he wants to say to communicate effectively and also the importance of listening, how to listen both in general and when receiving feedback specifically.

- **The leader role:** Students highlighted how important it is to have a leader in some groups, although a leader may not always be needed, and that a good leader can bring out the best in people.

- **How to work effectively in a group:** Students highlighted the importance of working effectively in a group and noted that many aspects affect the group work, e.g., communication, group formation, group processes, personal responsibility in group work, being able to take and give criticism within a group, and addressing conflicts before they explode, even if it is difficult. One student had the following comment:

  > *"I take with me how in groups you may need certain types of people and also that a leader may not always be needed."*

- **Learning about the engineering profession** - Students reported that they gained insight into the skills that are considered important to an engineer and the importance of professional skills for the engineering role.

3. Seminars are rewarding - After each dialog seminar students were asked about how rewarding they thought the dialog seminar and the related assignments were on a scale from 1=not so rewarding to 6=very rewarding, see Table 2. In the fourth survey the students were asked to choose the most rewarding elements in the course, and according to the survey the dialog seminar was the most rewarding element of the course, see Figure 4. Many students commented that they wanted to choose other moments, but since they were forced to choose one, they chose the most rewarding one. The following issues were identified from students' comments on what worked well in the seminars and what should be changed in the seminars:

- **Learning together through discussions and experience exchange with supervision:** Students appreciated the opportunity to have discussions with other students since they exchanged experiences, shared knowledge, and gave tips to each other, which provided useful new perspectives on certain things that they might not otherwise have thought about, for example to take ideas that had worked for others and test them for themselves.

Several comments stressed the importance of having an open atmosphere during the discussions, that students and mentors respected each other, and that the safe atmosphere in the dialog seminars helped students share their own experiences, thoughts, and feelings. Students also addressed the importance of the seminar leaders for managing the quality of the discussions and creating a trustworthy and open atmosphere. Some of the students had the following comments:

"I think the dialog seminar has good structure and leads to good discussions. It was also good that our mentor could help by asking good questions when it got quiet."
"It felt like you were in some kind of group therapy"
"Everyone got to speak and the mentor did a good job of letting us talk, but at the same time keeping the discussion alive"

Table 2. How rewarding are the seminars and related assignments according to the students

Dialog seminar number	Dialog seminar	Related assignments
1	4.64	4,21
2	4.57	3.92
3	4.77	4.87 (engineering profession)
		4.13 (teamwork)

- **Seminars made it possible to see differences and similarities:** Students mentioned that they developed an understanding that people work differently and that something that works for one person does not necessarily work for another person. Students also highlighted that they felt that they both recognized themselves in each other and understood that they had different challenges in some cases and similar challenges in other cases, e.g.:

  "I've learned that we all sit in the same boat – even though we can't see each other in it. We all have similar problems and try to solve them in a similar way. Everyone has problems with social contact, motivation, and monotonous everyday life. It feels good to know that you are not alone and can take comfort from it. I also got a lot of good tips on how to do things better or differently."

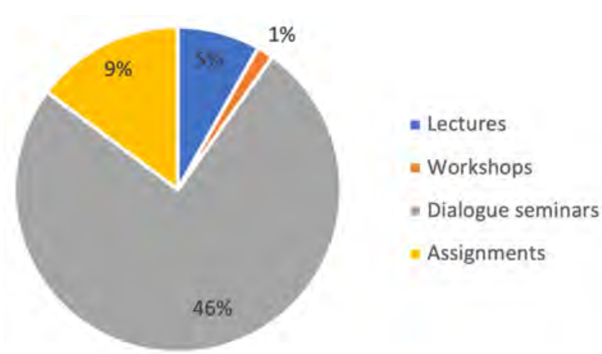

Figure 4. Elements of the course that have been rewarding.

- **Obligatory assignments, preparations, and seminars contribute to learning professional skills:** According to some students, the requirement of doing the assignments before the seminar was troublesome, but doing the assignments helped them to get insights about themselves, gave them the opportunity to do things in different ways than they were used to, and forced them to reflect. It is also important that obligatory active participation in the seminar was part of the examination, since it forced the students to be active, ask questions, and contribute to the discussions. This led to students being engaged in the discussions, which was very important for their learning. Groups with less engaged students got less out of the discussions. The mentors adapted the structure of the discussions to the students' level of engagement.

DISCUSSION

In the online professional skill course, students learn professional skills through the activities in the course and knowledge is gained when performing course activities focused on the specific topic (e.g., obligatory assignments) but also during discussion among students in online seminars.

Focusing on the three types of interaction (student interaction with online content, student interaction with remote teachers, and student interaction with distant student peers) is important in online courses (Abouhashem et al., 2021; Bernard et al., 2009; Luo et al., 2017) even for teaching professional skills. In the course, lectures were scheduled and given online by the teacher with the possibility of interaction with the students (enabling student interaction with remote teachers). With a modification of having online dialog seminars, the dialog seminar method was applied in the same way as in the professional skills course with face-to-face teaching (Berglund, 2018; Berglund & Heintz, 2014), enabling both student interaction with distant student peers and student interaction with remote teachers. We believe that this contributed to the positive outcome of the course since students' engagement in online courses is increased when students think, reflect, engage, and learn collaboratively with other students (Aderibigbe, 2020). However, a challenge in online discussions is turn-taking, where students talk over each other more easily compared to face-to-face seminars. One of the benefits of online dialog seminars is that the students do not have to print the texts in advance to bring them to the seminar as is required for face-to-face seminars. The students can only share their texts on the screen, which is easier for the students and beneficial from an environmental perspective. Another drawback of online seminars is that in face-to-face seminars students interact with each other during the break, which is not possible in online seminars since students leave the online session during the break. Therefore, the students might get to know each other less in online courses, leading to less networking among the students.

To have a successful implementation of the dialog seminar method online it is important that the video camera is used during the dialog seminars. When groups work together remotely and use video in addition to audio the quality of their work is the same as in face-to-face work, which is not the case if only audio is used (Olson, Olson, & Meader, 1995). Using cameras in online teaching helps to build teacher-student and student–student relationships (Castelli & Sarvary, 2021). The camera provides "virtual eye contact" that can create engagement during the discussions. When students look directly into the camera it will give the impression that they are directly speaking to each other and looking right at each other. Another benefit of using the camera is the ability to communicate with nonverbal cues such as smiles, head nods, looks of confusion, and looks of boredom, which help the seminar leader to evaluate the situation in real time and adjust accordingly to improve student learning. Students benefit similarly from being able to see other students during seminars since they can see how the other students react to things they say. The use of video helps build trust with other students in the group and develops a sense of identification with others (Falloon, 2011). Students learned during the discussions in the seminars when they exchanged experiences, shared knowledge, and gave tips to each other and they stressed the importance of having an open and safe atmosphere during the discussions so they could share their own experiences, thoughts, and feelings. The seminar leader plays an important role in creating a trustworthy and open atmosphere.

CONCLUSION

This paper describes students' experiences and lessons learned from an eight week reflective and online course in teaching professional skills that was applied in two bachelor engineering programs. According to our experience, professional skills can be taught successfully in online courses and applying a dialog seminar method in an online course is a suitable pedagogy for learning professional skills since, during the online dialog seminars, students think, reflect, engage, and learn collaboratively with other peers.

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BIOGRAPHICAL INFORMATION

Aseel Berglund, PhD is an Associate Professor in computer science at Department of Computer and Information Science at Linköping University (LiU). Her research focus is in game development, serious games, and gamification studying how principles, mechanics and techniques used in games can be applied in other environments and contexts that are not games for the purpose of motivating, engaging, and reinforcing positive behaviors or changing behaviors. Aseel is interested in pedagogical issues and she is passionate about teaching. She wants to inspire and contribute to students' development in both professionalism and subject knowledge. Aseel's ambition is for students to learn knowledge and skills that they can apply in personal and professional life.

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DEVELOPMENT OF MEANINGFUL LESSON USING LXD METHODOLOGY FOR AN ENGINEERING MODULE

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ABSTRACT

According to literature, learning is most meaningful when it is deliberately applied in real-life contexts by incorporating real-life contexts that facilitate active, constructive, intentional, and collaborative engagement into learning. This will help learners to achieve longer retention of what they have learned compared to memorising and rote learning. In Nanyang Polytechnic, Singapore, a Learning Experience Design (LXD) Methodology was developed to guide and support educators in the design of good learning experiences that are meaningful to learners and to achieve our goal of engaging and effective teaching and learning. This paper explains how we developed the meaningful lessons for an engineering module, focusing on application, problem-solving and collaboration. To examine whether the learners perceived the learning to be more meaningful after attending the lessons that are redesigned using the LXD methodology, a comparison study was conducted involving about 90 learners in the Diploma of Robotics & Mechatronics. The results indicated that learners in the experimental group perceived more meaningful learning and scored higher in the post-course test than the control group. In addition, the reflection on our experiences in going through the four recommended processes in the LXD Methodology, namely learner discovery, supporting learners in attaining learning outcomes, designing the learning experience, and evaluating for improvement will also be discussed. These reflections can be used as a case study to share with other educators who would like to design meaningful lesson to achieve a more engaging experience for learners. The last part of the paper highlights the challenges faced and provides improvement to further fine-tune and streamline the on-going implementation effort.

KEYWORDS

Meaningful learning, Learning Experience Design, Statistical Analysis, Standard 8 Active Learning, Standard 10 Enhancement of Faculty Teaching Competence

INTRODUCTION

Assimilation theory of learning, used to describe how human is engaged in meaningful learning, is an educational concept introduced by Ausubel (Ausubel, 1963) and later adopted by numerous researchers and psychology educators (Novak, 2007). Meaningful learning refers to binding new knowledge with preliminary information, cognitive mapping structure according to new learnings, and transferring them to daily life (Ausubel, 1963). Therefore, meaningful learning will help learners achieve longer retention of what they have learned compared to memorising and rote learning (Vallori, 2014). In other words, meaningful learning is to incorporate real-life contexts that facilitate active, constructive, intentional, and collaborative engagement into learning. Learning is most meaningful when it is deliberately applied in real-life contexts. Learners can then appreciate what they learn and apply it to new problems. In addition, collaboration is also an essential component of meaningful learning as humans learn better when we are in communities (Johannes, 2006) (Jonassen D. , 2005).

Meaningful learning also provides a model to help educators understand, implement, and evaluate concept-based teaching and suggests that meaningful learning occurs when new experiences are related to what a learner already knows (Teresa J. Getha-Eby, 2014) (Ang & Ngu, 2014). In a further development in 2003, Jonassen and his colleagues applied a constructivist perspective to using technology in schools to create technology-based activities that supported meaningful learning. They defined meaningful learning as occurring when learners were actively engaged in making meaning and identified five attributes of meaningful learning – "Active, Constructive, Intentional, Authentic and Cooperative" with the most meaningful learning activities supporting combinations of these attributes (Jonassen, Howland, Moore, & Marra, 2003). In 2012, Howland et al. demonstrated numerous examples of how different learners could use different technologies for meaningful learning. They also discussed the Assessing Meaningful Teaching and Learning rubrics which give educators a tool for reflecting on their practice (Howland, Jonassen , & Marra, 2011).

THEORECTICAL BACKGROUND

Meaningful learning is an important pillar in the Learning Experience Design (LXD) Framework (Figure 1) that was developed in Nanyang Polytechnic (NYP), Singapore in 2022. LXD (Floor, 2023) is the science and the art of creating experiences that helps learners fulfill the learning outcomes they desire, in a user-centered and goal-directed way. In NYP, the LXD Methodology embodies LXD principles, best practices, and research findings, and it is about creating Meaningful, Motivational and Memorable learning experiences that address the needs of learners, achieve the learning outcomes, and build propensity for life-long learning. It guides lecturers through the four processes in LXD, namely learner discovery, supporting learners in attaining learning outcomes, designing the learning experience, and evaluating for improvement, in a cyclical and iterative manner, with the goal of creating and conducting engaging teaching and learning. Teoh’s study (Teoh) demonstrated that using NYP LXD Methodology to design lessons for an engineering module based on learner's need and motivation, which is one of the domains in user experience and instructional design, increases learners’ level of understanding.

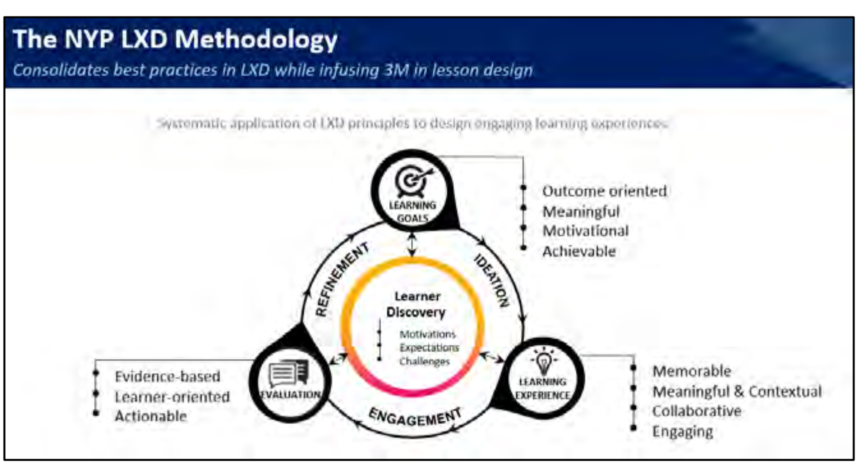

Figure 1: NYP LXD Methodology/Framework

This study sought to describe how we developed the meaningful lessons for the topic on Encoder of an engineering module, guided by NYP LXD Methodology and aimed to increase the confidence of learners in working collaboratively and responsibly with others, leading to a more meaningful learning on Encoder. This paper is divided into three sections. Part one provides an overview of the background on why the topic on Encoder was chosen and the two questions this paper will address. Part two deals with the research methods and part three discusses the results and the last part we will make a conclusion to this study.

Encoder (Realpars, 2023) (Fun, 2023) is one of the challenging topics that learners need to complete in a Year 2 engineering module from the Diploma in Robotics & Mechatronics (DRM). Before applying LXD Methodology, we taught encoder using National Instrument Sensor Training board (Figure 2) and focused on theoretical aspect where learners lack of appreciation on where and how the encoder can be applied. While some attempts, such as video curation, were made to link Encoder to real-life context in past few years, many learners still find the topic to be abstract and have difficulty linking the theory to real life application. And the test score for the topic on Encoder was always low compared with other topics in the same module. Hence, we embarked on an action research project to redesign our lesson and activities guided by NYP LXD Methodology focusing on the meaningful aspect of the NYP LXD Methodology.

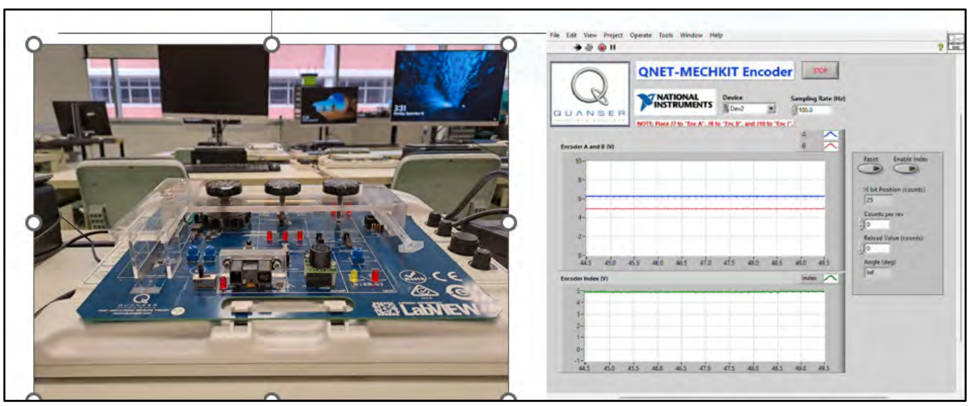

Figure 2: Encoder training before LXD implementation

The meaningfulness in NYP context, focus on 3 dimensions: application, problem solving and collaboration. For application, it is defined as the ability to use the learned materials in new real-life situations. This may include the application of rules, methods, concepts, principles, law, and theories. For problem solving, the definition adopted is the synthesis of learning and application in new and different situations to propose solutions and consider alternatives to a problem. For collaboration, the definition adopted is that learning occurs when two of more learners learn together through dialogue and social interaction, considering each other's perspectives and experiences to solve problems and develop a shared understanding of meanings. The first question that we would like to address is therefore the extent of learners perceiving the learning of Encoder to be more meaningful after attending the lessons that are redesigned using the LXD Methodology.

The NYP LXD Methodology is new and there was limited information on how NYP LXD Methodology leads to the design of learning experiences which are meaningful. Hence the second question we would like to address is the usefulness of NYP LXD Methodology in helping lecturers to design meaningful learning experiences for learners.

METHODS

Participants

The study involved about 90 Year 2 engineering learners from DRM. The first group (n = 46, control group) used the existing curriculum in Oct 2021 semester (2021 S2), while the second group (n = 45, treatment group) used the enhanced curriculum which was redesigned for meaningful learning in April 2022 semester (2022 S1). For both the control and treatment groups, the instructors and learners met face-to-face twice per week, once for the 2-hour practical session and again for a 1-hour problem solving tutorial. The participants were not randomly assigned to either the control or treatment group, rather we assigned 2021S2 batch as the control group and 2022S1 batch as the treatment group. Both groups were conducted by the same instructors and the module is a 15-week, compulsory module for all learners from DRM. Ethical approvals for data collection and leaner consent were obtained before its implementation.

Research Design

The NYP LXD Methodology provides a systematic application of learning experience design principles to guide staff in the process of creating and conducting engaging lessons. The four LXD processes were implemented as follows:

(1) Learner Discovery – the aim of this first process was to allow staff to empathize with our learners and it involved three steps:

Step 1: We conducted a Focus Group Discussion (FGD) with learners to have an in-depth understanding of their learning experiences on Encoder in terms of meaningful learning domain. 12 learners from control group who went through the existing curriculum on Encoder in 2021S2 were invited to the FGD. The FGD was facilitated by two instructors using the following guiding questions as shown in Table 1.

Table 1: Guiding Question for FGD (Control Group)

Q1	Is the encoder topic very difficult to learn? Why or why not?
Q2	Which part of the delivery of Encoder helps you to learn better/interests you the most?
Q3	Based on your years of study at NYP, recall a difficult topic that you have learnt well
Q4	What was that topic and what was the most important thing the lecturer did in that module to help you learn well?
Q5	Do the class activities (Lecture/Tutorial/Practical) allow you to apply problem-solving skill?
Q6	Do the class activities (Lecture/Tutorial/Practical) make you think about a problem and try to solve it?

Step 2: Once we gathered the input from the 12 learners through the FGD, we consolidated their responses into Persona

Step 3: Once we had a good understanding of the Persona, we used this Persona to design the learning experiences

(2) Learning Goals – the aim of this second process was to support learners in attaining learning outcomes by listing down the learning outcomes on Encoder that the learners need to achieve

(3) From Ideation, Learning Experiences to Engagement – with the learning goals and the persona at hand, we redesigned the learning content and activities on Encoder to be in line with the learners' abilities and needs in this third process. We followed the criteria for lesson design of the three dimensions on meaningful learning closely, namely application, problem solving and collaboration. In terms of application of Encoder, we contextualized the lesson to real-life situation and facilitated the application of learner knowledge and skills gained from the classroom learning to real-life settings. In terms of problem solving, we infused critical thinking in lesson design by designing activities to develop learners' problem-solving, questioning, and critical thinking skills. In terms of collaboration, we incorporated activities that requires learners to work collaboratively and share responsibility. Figure 3 shows a real-life measuring wheel laboratory kit using encoder.

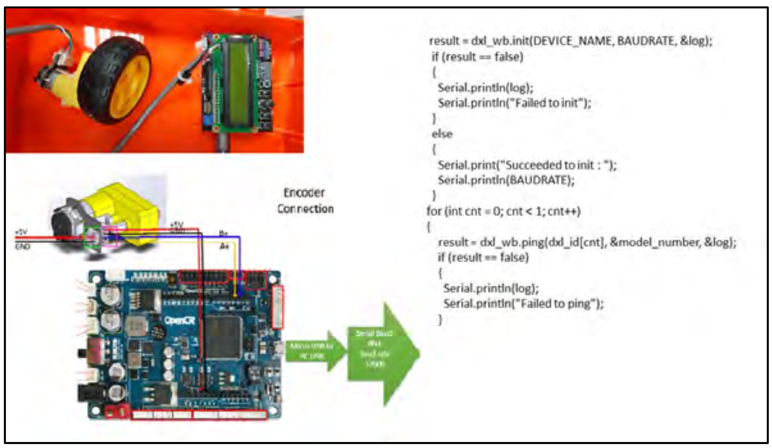

Figure 3: Measuring wheel laboratory kit development

(4) Evaluation to Refinement – the aim of this fourth process was to collect data about the redesigned lessons to allow staff to know whether the redesigned lessons on Encoder provide meaningful learning experiences for the learners. One key consideration was to choose the survey instruments to be administered to learners to measure their meaningful learning experiences. The other consideration was to decide on the platform to be used to administer the survey to learners.

To address the second question on the usefulness of NYP LXD Methodology in helping lecturers to design meaningful learning experiences for learners, we documented our experiences in a reflection journal as we walked through the four processes. For example, in the first process of learner discovery, we documented our experiences on choosing the participants (i.e., volunteering, nominated, sampled), getting participations from learners in the FGD, and crafting the guiding questions that are aligned to the LXD methodology. Another example would be in the third process, we documented our experiences which include key design decisions and justifications in the redesigning of the lessons on Encoder and key consideration in choosing the tools to be used to develop the learning materials and activities.

DATA ANALYSIS AND RESULTS

Data Collection

To answer the question on, to what extent do learners perceive the learning of Encoder to be more meaningful, we conducted a quantitative survey in 5-point Likert Scale (Strongly disagree

-1, Disagree – 2, Neutral – 3, Agree – 4, Strongly Agree -5) to 46 learners in control group in 2021S2 and 45 learners in treatment group in 2022S1 where the profile of these two groups of learners was similar. The survey instruments that were administered to learners can be found in Table 2.

Table 2: Quantitative Survey Questions (NYP LXD)

Q1	Meaningful	Application	The lessons provide opportunities for me to apply acquired knowledge & skills.
Q2		Problem-Solving	The lessons provide opportunities for me to develop problem-solving skills.
Q3		Collaboration	The lessons allow me to collaborate with my classmates more often.
Q4	Motivational	Attention	The lessons captured my interest and inspired me to explore more about the topics taught
Q5		Autonomy	The lessons incorporate materials and activities that allow me to choose the pacing and intensity of learning
Q6		Confidence	The lessons allow me to achieve small success while I progress to achieve the learning goals
Q7	Memorable	Appreciation	I can appreciate the learning content and objectives because they were clearly introduced
Q8		Connection	I am given the opportunity to express my feelings freely while exploring ideas during lessons

While our study focuses on the meaningful domain of LXD, we decided to collect data on the motivational and memorable domains as well to examine how the change of redesigning lessons in the meaningful domain impacts to the motivational and memorable domains.

Data Analysis

Figure 4 tabulates the mean values of the quantitative survey data from both groups. It shows an overall increase in rating by treatment group for all the 8 questions, indicating that learners from treatment group perceived the redesigned material to be more meaningful, motivational and memorable.

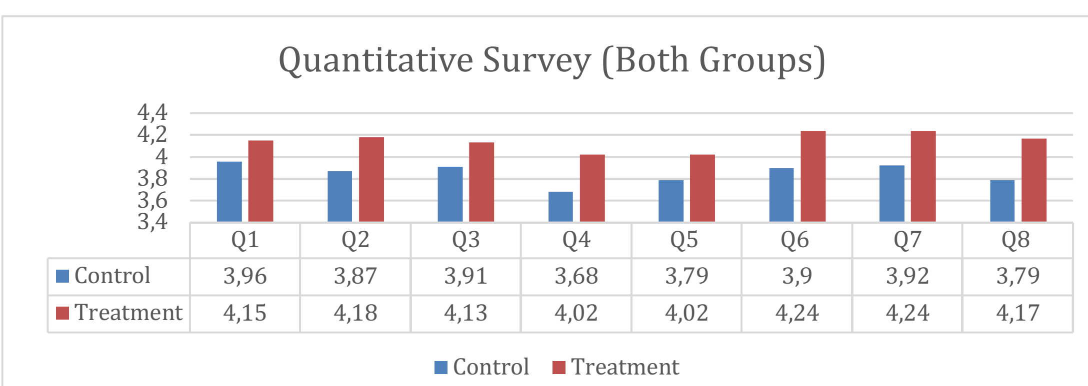

Figure 4: Quantitative survey for both groups (5-point Likert Scale)

To exam how significant difference in perceiving meaningful learning among control and treatment group, we carried out a statistical analysis to the quantitative survey data. Paired samples t-test is normally used to test if the means of two pairs measurements, such as pretest/posttest scores, are significantly different [15]. Hence, we conducted paired sample *t*-test, set test value alpha as 0.05 and hypothesized mean difference as 0 and obtained the value of p in Table 3.

Table 3: Paired Sampled t-Test Result

	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8
P(T<t) two-tail	0.020	0.0065	0.16	0.02	0.08	0.02	0.021	0.016

We observed that p values for all the questions are less than the test value alpha of 0.05 except for Question 3 on Collaboration and Question 5 on Autonomy.

The findings implied that learners did find the redesigned Encoder lessons to be meaningful in the application and problem-solving dimensions. Perhaps in our design of collaborative learning activities, instead of assuming that learners know to work collaboratively, we should first introduce the meaning of collaborative learning to learners, in terms of how they should explain concepts, justify and defend their perspectives and approach to others in a cordial and respectful manner.

It is interesting to note that learners would prefer lecturers to incorporate materials and activities that allow them to choose the pacing and intensity of learning. This is so that they are given some degree of choices in what they want to learn and how they want to learn. Perhaps we could investigate this aspect of personalized learning as we continue to improve the lesson materials and activities on Encoder.

Documentation and Reflection

To answer the question on how LXD Methodology helps lecturers to design meaningful learning experiences, we document our critical design decisions and justifications of the lessons on the encoder and the key consideration in choosing the tools to develop the learning materials and activities. We also documented our thoughts and opinions - these include what we like, what kind of improvement we would like to see, any questions or related question that came up from the idea or setup, and any other ideas that we can explore that will enhance the lesson.

We found that the LXD Methodology is valuable to help lecturers design meaningful learning experiences for our learners as it provides a set of lesson design criteria that guides lecturers in creating and conducting engaging learning experiences. It can help us to focus on the three dimensions (meaningful, motivational, and memorable) one at a time. Lecturers can begin the LXD processes from any dimension, and the impact of engaging learning experiences will be enhanced in all three dimensions.

In addition, it is challenging to engage all the learners participating in our survey (92 participants out of 130), and a lot of time is needed in designing, documenting & delivering meaningful redesigned lessons and activities than the regular curriculum.

Finally, we reflected by triangulating two data sources, the recorded journals and the learner's feedback from the Focus Group Discussion. We felt that the measuring wheel laboratory kit and the redesigned lesson improved and addressed the initial struggle of the student not finding meaningful in the study.

CONCLUSION

We found the LXD Methodology to be useful in designing meaningful learning experiences for our learners as it provides a set of lesson design criteria that guides lecturers in the creation and conduct of engaging learning experiences. There is no need to focus the lesson design on the three dimensions (meaningful, motivational, and memorable) in one go. Lecturers can begin the LXD process from any dimensions and the impact of engaging learning experiences will be enhanced in all three dimensions.

We managed to reflect and journal our experiences in going through each of the four recommended LXD processes. While it is time consuming to document each step of our journey in re-designing the lessons and activities on Encoder, we realized that this process of documentation and reflections provides us an opportunity to perform self-observation along with self-evaluation. It is important because we can identify the kind of LXD processes that we took, analyzed the thoughts we had in how we deliver the lessons and evaluate the outcome for future improvements including decision making, justification on specific contents, delivery methods, learner survey and challenge faced. It can be shared with lecturers who are interested in developing meaningful lessons to learners. These reflections also provide opportunities for us to recommend further refinements to the LXD processes. The next step is to collect feedback from other lecturers on the usefulness of these case studies.

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MECHANISED BRIDGES: DEVELOPMENT OF A NOVEL, MULTIDISCIPLINARY, DESIGN AND BUILD PROJECT.

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ABSTRACT

We developed a new common core first-year "introduction to engineering" unit at Monash University, the number one Engineering school in Australia (THE, 2023). The requirements for the unit and its team-based project were to span multiple engineering disciplines, especially Civil and Mechanical, and to scale effectively for up to 900 students per offering. The relevant CDIO standards were applied in the unit design process to understand the context, ensure curriculum integration, devise appropriate learning outcomes, and develop a major team-based design-and-build project. The project was scaffolded via weekly active learning in-class activities and assessments. We had the advantage of delivering this new unit in brand new teaching spaces, which we designed specifically for first-year teaching. Our specialised learning spaces feature flexible, teamwork-configured furniture, ample power, secure storage and a large fleet of 3D printers. Students access Computer-Aided Design Software on their own devices, allowing them to continue working outside formal class time. These facilities and the project design allowed student teams to engage in a very practical and hands-on way with the unit content, via design, build and testing. Program evaluation following the first offering showed strong student satisfaction and development of skills in 3D printing and teamwork (Tong et al., 2022) associated with the new unit and the "bridge mechanism" design project.

KEYWORDS

Design project, first-year, 3D printing, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 12

INTRODUCTION

This paper uses a CDIO framework to document the development of a new design-and-build, team-based project for a first-year introduction to engineering course at Monash University, Australia. The Faculty of Engineering has only recently joined CDIO, so this process familiarised many of our engineering design academic staff with the CDIO standards, stages and processes. Throughout this paper, we refer to the subject level as 'unit' and the program level as 'course', consistent with our university's nomenclature.

CONTEXT

First-year engineering at Monash University consists of eight units of study, four each semester for two semesters (Monash University, 2023). Three of these units are reserved to allow students to catch up on any foundation maths, physics or chemistry they may have missed from their high school studies and to allow for electives. This leaves five common core units in the first year that all students must complete - four engineering units and one maths unit. Monash University offers a comprehensive range of engineering specialisations (ten in total) in a four-year Honours level program, with specialisations chosen by students from the second year onward. Our degrees, offered at both our Australian and Malaysian campuses, are accredited by Engineers Australia to the Stage 1 Competency Standard (Engineers Australia, 2019).

In 2018, the Faculty of Engineering embarked on a major review of our common-entry, first-year engineering program, which had not received any major revisions or updates since its first design in 2014. This review took in a wide and diverse range of stakeholder feedback, including that of academic staff, students, alumni, and local industry. Our common first year introduces the fundamental engineering concepts that underpin Sustainable Smart Cities and the critical engineering design processes required to solve related problems. Our first-year students are exposed to:

- the construction of safe and sustainable structures and mechanisms, and examining how complex problems can be addressed (in ENG1011);
- the design of critical water treatment processes and the ethical, environmental and sustainability considerations of such systems (in ENG1012);
- the software and electrical systems required to enable it all to work in a coordinated manner (in ENG1013);
- how to use computers to solve complex numerical problems that arise in engineering (in ENG1014);
- And how to use mathematics to model these problems and to be able to solve them (in ENG1005)

This paper will utilise the lens of CDIO (Malmqvist, J., 2019) to first consider all three of these new design units (ENG1011, ENG1012, ENG1013) in terms of their context, curriculum and integration (Standards 1 and 3). We will then focus on one unit (ENG1011) in greater depth and consider how we addressed Standards 2, 4, 5, 6,7, 8, and 12 in its design, delivery and initial evaluation.

STANDARD 1: THE CONTEXT AND
STANDARD 3: INTEGRATED CURRICULUM

The basic introductory technical content for these three new design units was divided on the following basis in an attempt to group cognate subject areas while also covering the required breadth:

- ENG1011 - Engineering Methods (Civil, Mechanical, Materials, Computer-Aided Design, 3D Printing)
- ENG1012 - Engineering Design (Chemical, Materials, Sustainability, Humanitarian, Ethics)
- ENG1013 - Engineering Smart Systems (Electrical and Software)

The units are mapped below for a typical Semester 1 entry (see Figure 1). Due to our mid-year entry pathway (common for international students), these first-year units are not prerequisites for each other and are designed to be attempted in any sequence (bar engineering maths, ENG1005, which is a co-requisite for the numerical analysis unit, ENG1014).

E3001 Bachelor of Engineering (Honours) Common first year

If no foundation units are required:

Year	Period	Units			
1	Sem 1 Feb	ENG1011 Engineering methods	ENG1005 Engineering mathematics Required: ENG1090 *	ENG1014 Engineering numerical analysis Corequisite: ENG1005	First Year engineering technical elective+ Or swap semester with an Elective unit
	Sem 2 July	ENG1012 Engineering design	ENG1013 Engineering smart systems	Elective	Elective

Figure 1. Revised first-year mapping showing three new core engineering design units.

These three design units were carefully planned to be complementary (rather than repetitive) in terms of their focus on professional skills development and their mode of assessment for team and project work. ENG1011 Engineering Methods was tasked with providing a particular focus on the following areas.

For professional skills:

- Development of team meeting skills: agendas, minutes, tasks, and progress tracking;
- Development of delegation skills: sharing of workload and scheduling work;
- Development of decision-making skills: considering, selecting, and justifying the best concepts;

For assessment modalities:

- Communication of project progress and outcomes using hand sketches, and Computer-Aided Design (CAD) modelling and drawings;
- Communication of project progress and outcomes using oral presentations, slide decks, animations, and multimedia (i.e. videos).
- Documentation of engineering analysis through report writing and calculations

STANDARD 2: LEARNING OUTCOMES

We operate in an outcomes-based education environment, whereby our Course Learning Outcomes align directly with the Engineers Australia Stage 1 Competency Standard graduate competencies. We utilise the SOLO taxonomy (Biggs, Tang & Kennedy 2022) to articulate the level of each assessed learning outcome and appropriately scaffold learning outcomes throughout the course, culminating in assessment pieces that are constructively aligned (Biggs, 1996). The ENG1011 team converged on six learning outcomes (LOs) for the unit.

1. Determine reactions and internal member forces in simple truss and beam systems and carry out limit state design to select appropriately sized members.
2. Determine the strength of structural materials to inform engineering designs with considerations to performance, cost, sustainability and societal impact.
3. Determine the steady-state performance of simple systems involving levers, gears, springs and pulleys using appropriate engineering problem-solving methodologies.
4. Propose concept designs that solve engineering problems and justify finalised design with considerations of key variables, assumptions and system boundaries.
5. Identify appropriate engineering tools and techniques to develop, validate and convey designs and solutions.
6. Identify roles and responsibilities within a team and reflect on self and team.

LOs 1-3 were allocated to each of the three major discipline areas covered by the unit (civil, materials, and mechanical engineering, respectively), and these were all pitched at a multi-structural level (level 2). The verb *determines* was used for all three of these LOs. The remaining three learning outcomes were allocated to design processes and methods (as per the title of the unit) at a multi-structural level using the verb *propose*; the identification and use of appropriate engineering tools (including CAD and 3D print slicer software) at a uni-structural level (level 1) using the verb *identify*; and teamwork roles, responsibilities, and behaviours, also at a uni-structural level also using the verb *identify*. The final LOs are presented in the unit handbook (Monash University, 2022).

STANDARD 4: INTRODUCTION TO ENGINEERING

CDIO Standard 4 recommends an introductory unit that *"provides the framework for engineering practice in product, process, system, and service building and introduces essential personal and interpersonal skills and the rationale of sustainability in the context of engineering."* As explained in the previous section, we took the approach of providing three units in the first year with such experiences. We balanced them with relevant fundamental technical knowledge in the spirit of Standard 7 Integrated Learning Experiences. We found this approach to be most equitable and politically expedient in our negotiations with discipline academics, some of whom favoured incorporating design and team project assessment elements, while others preferred to avoid any design or open-ended assessment elements. By approaching each unit (and engineering discipline) from a design and teamwork perspective, we hoped to avoid reinforcing unconscious biases that certain disciplines are more theoretical/individual and others are more practical/collective. First-year students tend to be inexperienced and often fearful about working in highly interdependent teams for any significant proportion of a unit's marks (Huang, 2021). In our anecdotal experience, early exposure to unfavourable teamwork experiences can negatively influence their opinions of the disciplines associated (Sekhar *et al.*, 2022). Given our students decide their disciplines at the end of the first year, these first impressions are critical as they impact student load, teaching revenue, and ultimately, department size, resourcing, and staffing.

Having three major team projects also gives us a greater opportunity to stimulate a student's interest and passion for a topic area or a particular approach to engineering practice. We believe that achieving such engagement is healthy for student confidence, well-being, and retention and is one of the first steps to helping them identify as engineers. This early sense of belonging within the profession is more important than ever, given the impacts on learning and student engagement resulting from COVID-19, which we are still experiencing.

STANDARD 5: DESIGN-IMPLEMENT EXPERIENCES

In ENG1011 Engineering Methods, students are introduced to fundamental aspects of civil, mechanical, and materials engineering. We selected static structural force analysis (equilibrium, reactions, truss and beam analyses) for the civil content, common mechanisms (springs, pulleys, gears, frames) for the mechanical content, and material properties (stress and strain) for the materials content. Considered together, we intended for students to have the theoretical foundations to design and analyse spaceframe-like structures to failure limits and to develop functional mechanisms. Computer-Aided Design (in our case, SolidWorks©) was taught in this unit to allow students to develop their ideas digitally and in three dimensions. The slicer software Cura© was also taught and utilised to enable students to 3D print their structures and mechanisms using twenty-four fused deposition modelling (FDM) 3D printers (Prusa i3 Mk3s+), which were supplied for exclusive use by students in this unit (more details in the Standard 6 section).

The major project spanned 5 weeks at the end of the semester. Teams of approximately five students were challenged to design and build a ***bridge mechanism*** that could:

- Fit within a restricted starting volume (a 100 mm sided cube);
- Extend/deploy/expand from its initial state, to span a gap several times its starting size (gap was 300mm);
- Support a specified mass at its mid-span (mass of 1kg).

Teams were provided with the following resources to prototype and realise their designs:

- an assortment of custom-designed “Meccano-like” structural members that were laser-cut from 3mm acrylic sheet, featuring 3mm holes at 10mm intervals;
- unlimited M3 nuts, washers and pieces of M3 all-thread rod in various lengths (50mm, 75mm and 100mm);
- unlimited use of elastic bands and tension and compression spring elements;
- unlimited builder’s string to use for tension-only members;
- unlimited PLA filament and regular access to FDM printers.

The requirements for the deployment of the bridge mechanism were strict to ensure teams created a mechanism with a single degree of freedom and to effectively outlaw the rapid assembly of disparate parts. These included:

- Mechanisms were to be deployed by the application of torque via a ¼” hex drive either in the form of an electric screwdriver or a hand-operated hex wrench.
- This action could power the deployment of the mechanism directly. i.e. via gears or linkages, or it could act to unlatch stored spring energy to power the mechanism.
- Deployment time was strictly limited to 30 seconds.
- Deployment was to be achieved via a single team member utilising one hand to support the mechanism and one hand to actuate the hew key or driver.
- The orientation of the mechanism was to be maintained consistently during deployment and when positioned to span the gap, to eliminate the input of gravitational potential energy via the operator during or after mechanism deployment.

Teams were explicitly required to incorporate at least one 3D printed component into their device due to the planned scaffolded class activities (CAD, slicing, and 3D printing) and the desired learning outcomes. Nearly all teams choose to 3D print at least the ¼" hex recess to accept the hex key to actuate or unlatch their device. Many teams designed and 3D printed the entirety of their mechanisms. Some example bridge mechanisms produced by teams are shown in Figures 2, 3, and 4.

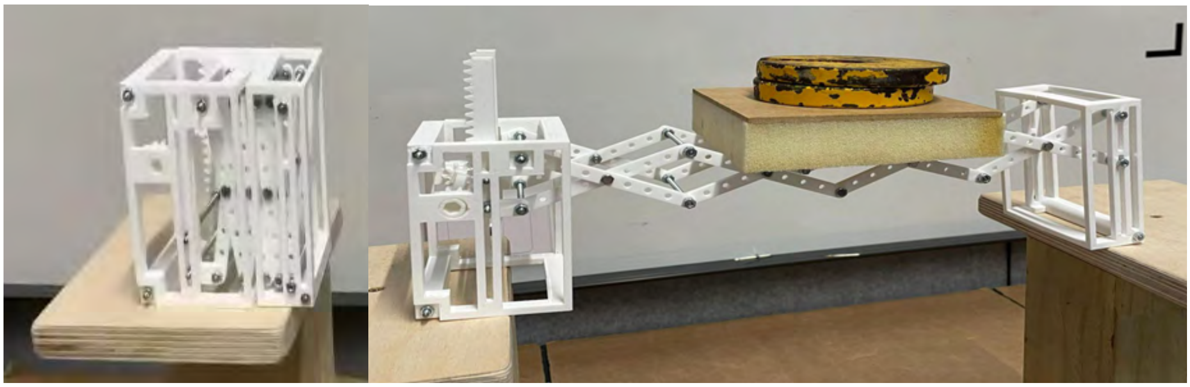

Figure 2: A bridge mechanism featuring rack-and-pinion and scissor elements prior to (left) deployment, and (right) the mechanism deployed to span the 300mm gap, supporting 1 kg.

Figure 3: CAD of a bridge mechanism utilising a threaded power screw, scissor elements and tension locking top panels in (left) pre-deployment and (right) post-deployment.

Figure 4: An elastic-powered bridge mechanism with hex-drive operated latch in its (left) pre-deployment and (right) post-deployment states.

STANDARD 6: ENGINEERING LEARNING WORKSPACES

A specialised “flat-floor” space with seating for 120 students was designed and built (as part of a large new building) for the weekly 3-hour practical sessions and associated project work in this unit. This venue is equipped with dry-erase tables on wheels that can be quickly folded and stowed, overhead power, audio-visual equipment, and large areas of the floor that can be easily cleared to make room for project testing (see Figure 5). The connected storeroom was used to stow the 24 dedicated 3D printers mounted on six rolling workbenches outside of class time. Each team was provided with a small combination locker to enable them to store their project kits close to the teaching space, allowing any subset of team members to access the materials and work on the project fluidly throughout the semester. Our students are required to provide their own laptop device, which meets a minimum performance standard required to install and run the required CAD and slicer software in class.

The venue’s facilities allow students to present physical and digital media of their choice. Presentations are often performed in up to three streams, aided by the provision of mobile audio/visual solutions in the form of Mobile Computers on Wheels (MoCoWs) to handle the demands of large cohorts (850+ students per semester, 120 students and 24 teams per session).

Figure 5: Our 120-seat, flat-floor teaching space (left). Two of our six mobile 3D printer workbenches, each featuring four Prusa i3 Mk3 printers and a ducted HEPA air filter (right).

STANDARD 7: INTEGRATED LEARNING EXPERIENCES AND STANDARD 8: ACTIVE LEARNING

Each week of the project represents a phase of the design process and moves closer to the ultimate goal of a realised product. The type of informal reporting typical of the engineering workplace is used for assessment early in the project, and a more substantial formal, summative presentation with a supporting slide deck is made at its conclusion. Different team members are required to present each week to ensure shared participation. Practical learning activities and assessment details are shown in Table 1.

Table 1: Project Assessment

Week	Primary Activity	Practical Learning Activities	Assessment (%)
1	Concept Ideation	Working in your team, develop one unique idea per team member that satisfies the project brief. Describe using hand sketches, or build a prototype using the kit parts.	Two team members present the team's three best ideas and describe relative merit. (1%)
2	Part/Assembly CAD	Two high-potential concepts are developed into functional CAD assemblies.	Two team members present CAD models and describe mechanism function and merit (1%)
3	Additive Manufacturing Study	Key details (fits, tolerances, critical geometry, print orientation, etc.) are prepared for 3D printing and test parts are manufactured.	Two team members present and justify their parts and additive manufacturing strategy. (1%)
4	Preliminary Testing	Teams manufacture prototype assemblies and are provided access to testing equipment. Instructors are available for consultation.	Peer assessment of design brief satisfaction and performance test criteria against a provided rubric. (1%)
5	Final Test	Teams demonstrate the function of their mechanism and present slides which explain their design, development and testing.	Two team members present and demonstrate their mechanism and critically analyse the entire design process. (9%)

STANDARD 12: PROGRAM EVALUATION

The success of this new team project was initially evaluated based on both quantitative and qualitative feedback collected as part of our university's Student Evaluation of Teaching and Units (SETU), summarised in Table 2. Overall, students were satisfied with the unit (3.83/5, above the university average score). This level of overall unit satisfaction was the highest among the three new design units. The survey results showed strong performance compared to previous semesters in criteria related to the mix of theory and practical application, engagement, learning activities and assessment. Students also self-reported growth in their skills relating to design project experience, CAD, 3D printing, and teamwork (Tong *et al.*, 2022). A large number of anonymous written comments were also received, and a couple of interesting ones relating to the project and scaffolded activities included:

“I really enjoyed the process of creating Solidworks models using the theory taught, 3D printing them, and testing. I found this prototyping loop to be a very effective way to teach the fairly abstract theoretical concept in a very hands–on way.”

“There was a good aspect of practical application, when it came to the practical classes, and the group work was challenging, but doable. This allowed for great student discussion and teamwork, which is the perfect environment for learning engineering.”

Table 2: Student Evaluation of Teaching Units Survey Results - ENG1011, S2 2022

University Wide Items (Summary)

	Responses	Median	%Strongly Agree/Agree
The Learning Outcomes for this unit were clear to me	133	4.10	78.95%
The instructions for Assessment tasks were clear to me	133	4.08	78.20%
The Assessment in this unit allowed me to demonstrate the learning outcomes	133	4.02	73.68%
The Feedback helped me achieve the Learning Outcomes for the unit	133	3.90	66.17%
The Resources helped me achieve the Learning Outcomes for the unit	132	4.00	68.18%
The Activities helped me achieve the Learning Outcomes for the unit	133	4.08	79.70%
I attempted to engage in this unit to the best of my ability	129	4.29	83.72%
Overall, I was satisfied with this unit	133	3.83	62.41%

Faculty Wide Items (Summary)

	Responses	Median	%Strongly Agree/Agree
The assessment tasks helped me to develop the knowledge and skills required for this unit	132	4.02	73.48%
I understood the grading criteria used in assessing my work	132	4.05	76.52%
This unit contained a good mix of theory and practical application	132	4.44	86.36%
The Moodle site was engaging and enhanced the learning experience	133	3.87	65.41%
The lectures were valuable for my learning	131	3.95	70.23%

Some comments included valuable recommendations for future improvements, including:

“Have smaller teams, 4 – 5.”

“One major issue throughout the semester was the lack of printers available. I think obtaining more printers or setting aside more time would make the process much more enjoyable… It felt like there was very little time and if a single print failed or a single idea failed, then there would not be enough time to complete another.”

RECOMMENDATIONS AND FUTURE WORK

For future iterations of the project, the following improvements will be made:

- Make 3D printers available on weekends and after hours. Limited access hours and competing with class time in other units of study may have limited the number of design iterations.
- Increase the weighting of the project assessment. The percentage of the total grade allocated was not seen to represent the time required to complete the project compared to other assessment tasks, as evidenced by students’ comments in SETU.
- In 2023, we will implement a First-Year Learning Centre - an informal space for first-year students to work on their projects, attend unit helpdesks and be referred to study support where necessary.

Recommendations to others pursuing a similar project implementation:

- Pedagogically speaking, high expectations of student output can be set as long as learning is scaffolded appropriately. We recommend regular design reviews with skilled

teaching staff to provide timely feedback, motivate regular progress towards the goal (rather than a sprint at the finish), and help detect teamwork problems early.
- Teams of 4-5 students are preferable for first-year projects, given the students' inexperience in managing engineering teamwork dynamics.

CONCLUSIONS

A design project was implemented in the unit ENG1011 Engineering Design, integrating elements of civil, mechanical, and materials engineering. The project required students to propose a range of solutions to a complex, open-ended problem and justify their chosen solutions with engineering reasoning. Students developed a bridge mechanism according to the given constraints for starting size, deployment span and structural strength. This type of open-ended project has traditionally been challenging for first-year students. However, students were encouraged to pursue novel and/or non-obvious solutions, which was assisted through the stages of conceiving, designing and implementing an engineering solution. This scaffolding allowed students to feel confident to 'have a go' and awarded students for exploration and decision-making. By giving first-year students the tools to identify a complex problem, break it into manageable stages and prototype a solution, we believe we have set them up for success in their future years of study as they tackle more open-ended, engineering problems.

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FUSING PROGRAMMING AND THERMODYNAMICS IN A FIRST YEAR ENGINEERING COURSE

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ABSTRACT

This paper describes a first-year undergraduate engineering course called Energy that has been developed and taught at the Department of Engineering at Reykjavik University. The aim of this course was to merge Matlab programming and thermodynamics into one course. In this course the students learn the fundamentals of thermodynamics and solve thermodynamic and energy related assignments using Matlab programming. Other courses that the first-year students are taking simultaneously also integrate Matlab into their curriculum to some degree. In the 2020 course the syllabus of Matlab programming and thermodynamics was fused together from day one, with many students having difficulty in learning the basic programming while taking in new theoretical relations of thermodynamics. This was changed in the 2021 course where the first 4 weeks of the course focused almost entirely on Matlab programming and the remaining 8 weeks focused on thermodynamics, where Matlab was used as a tool to solve problems. In 2022 this was split into two courses, one 4 weeks Matlab course and one 8 weeks Energy course where students continue to use Matlab. The course is being developed further, but the main feedback from students is that they prefer the content of programming and thermodynamics to be distinguished to some extent. Developing this course is in line with the CDIO standards 3 and 4; Integrated curriculum and Introduction to engineering where students get real data to work with which relates them more to modern and current engineering challenges in energy related topics. This will prepare them for working on the energy challenges the world is now facing.

KEYWORDS

Curriculum Change and Curriculum Agility, Sustainability in Engineering Education, Standards: 3, 4

INTRODUCTION

Undergraduate study in engineering at the Department of Engineering (DE) at Reykjavik University (RU) in Iceland aims at providing solid background for specialization in different engineering study lines and prepare students for graduate study and engineering profession. Annually around 200 students are enrolled into the first year of the following BSc programs: Financial Engineering, Engineering Management, Biomedical Engineering, Mechatronics, Energy Engineering, Mechanical Engineering and Electric Power Engineering. DE at RU has been implementing the CDIO approach into its curriculum for more than a decade (Audunsson et al. (2020) and Saemundsdottir et al. (2012)

Programming is an essential factor in the engineering curriculum and it has been a core subject in undergraduate studies of all engineering study lines taught at RU. The students who are enrolled into the engineering programs come from different secondary schools and many of them have little or no experience in programming while other students have graduated from specific computer science programs. To get the students to a similar page when it comes to programming, Matlab programming has been used as the first programming language they learn at RU and it has been taught in a specific Matlab course. Matlab is considered to be a relatively simple and a user-friendly syntax which works well for engineering students with little or no background in programming, and it has been widely taught in engineering curriculum (Bettin et. al, 2022). At RU a 6 ECTS course in Matlab programming has been taught for first year engineering students since year 2009 and after completing that course students have taken another 6 ECTS course in a computer language like C++ or Python. Earlier this was considered to be a successful setup but in recent years, students are more frequently using Python instead of Matlab in other courses and thesis work in later years of their studies. That fact has shifted the emphasis from a whole 6 ECTS course in Matlab programming into learning only the basics of Matlab programming and integrating these skills into other courses. This has been successfully integrated in many other programs at technical universities, an example of a CDIO approach to this can be found in a paper by Enelund et al. (2011).

In Iceland, almost all of the electricity is produced from renewable energy sources like geothermal and hydropower (Energy Statistics, 2022). The country has a unique opportunity to phase out fossil fuels in their transportation sector. The current energy transition aims at replacing fossil fuels with renewable energy, either using electricity directly or by producing E-fuels (e.g. hydrogen and ammonia) as energy carriers. Iceland aims for carbon neutrality by 2040 (Gov. of Iceland, 2020) and the energy and transport sector will be one of the biggest contributors to fulfill that goal. It is therefore important that all engineering students in Icelandic universities get a solid background in thermodynamics and knowledge of the energy sources, since it is likely that they will be required to have these basic skills in their future employment, regardless of which engineering study line they have selected. This subject is also an excellent platform in a university course to integrate with the basics of programming to perform calculations, import data and present results e.g. in spreadsheets and graphs. This outlines the motivation for the development of the new first year course in undergraduate engineering studies at RU that is described in this paper.

The aim of this paper is to describe the development of the new course Energy at RU which has been in the engineering curriculum since 2020 and how the lessons learned have led to changes in that course over the past 3 years this course has been taught. During the course development the CDIO Standard 3 for Integrated curriculum as well as Standard 4 of Introduction to engineering (CDIO, 2023) have been implemented.

THE ENERGY COURSE

Background

In 2019 when a new Dean of Department of Engineering and a new Department Council came on board at RU, they decided to do curriculum changes to the study lines offered at the department. For the study lines Financial engineering and Engineering management two courses; Chemistry (6 ECTS) and Thermodynamics (6 ECTS) were removed as mandatory courses. Also, all students now take a course in Python programming in the second semester. This initiated changes to how programming and thermodynamic courses were taught for the first-year undergraduate students.

It is very important that all engineers have fundamental understanding of thermodynamic processes and how energy conversion takes place and which limitations apply according to the laws of thermodynamics. In particular, basic practical knowledge of thermodynamics and energy technology is of special importance in Iceland due to the current energy transition. Therefore, since some study lines do not have thermodynamics as a mandatory course anymore and students learn programming in Python already in second semester, it was decided to merge introductory thermodynamics and energy technology together with practical programming in Matlab into one course, called Energy. It is to be noted, that some study lines (e.g. Mechanical and Energy engineering) still have mandatory courses in Chemistry and Thermodynamics later in their curriculum. The 1st year curriculum prior to and after these applied initial changes are shown in Table 1 where the changes made to the prior curriculum (Table 1a) are shown in italics in Table 1b.

Table 1. Curriculum for 1st year BSc Engineering prior to and after the curriculum changes made in 2020. Changes from previous curriculum (a) are shown in italics in (b).

Autumn Semester 1st year	
a. Prior to curriculum change	**b. After the curriculum change**
Calculus I (6 ECTS)	Calculus I (6 ECTS)
Physics I (6 ECTS)	Physics I (6 ECTS)
Chemistry (6 ECTS)	*Linear algebra* (6 ECTS)
Practical Programming in Matlab (6 ECTS)	*Energy* (6 ECTS)
Brainstorming (1 ECTS)	Brainstorming (1 ECTS)
Introduction to Engineering (5 ECTS) (3 weeks)	Introduction to Engineering (5 ECTS) (3 weeks)
Spring Semester 1st year	
a. Prior to curriculum change	**b. After the curriculum change**
Calculus II (6 ECTS)	Calculus II (6 ECTS)
Physics II (6 ECTS)	Physics II (6 ECTS)
Linear Algebra (6 ECTS)	*Engineering programming* (6 ECTS)
Study line specific course (6 ECTS)	Study line specific course (6 ECTS)
Entrepreneurship and Starting New Ventures (6 ECTS) (3 weeks)	Entrepreneurship and Starting New Ventures (6 ECTS) (3 weeks)

Course description

Following is the initial course description and learning outcomes of the 6 ECTS course Energy which was launched in autumn semester 2020.

Course description
At the beginning of the course the students will learn the basics of programming tools, e.g. Matlab to solve engineering problems. This tool will be used in the course in project work. The basics concepts and laws of physics which relate to thermodynamics and heat transfer will be introduced. An emphasis is made on conservation of matter, mass and energy in simple systems. Thermodynamic properties of pure substances and laws of

thermodynamics, and ways of heat transfer will be introduced as well as analysis of energy sources for thermal energy and electricity production.

Learning outcomes:
At the end of the course the students should have knowledge of:
- The fundamentals of engineering which relates to thermodynamics
- Energy and mass conservation in simple engineering systems
- The physics of heat transfer
- Practical programming for solving engineering problems

At the end of the course the students should have competence to:
- Solve simple engineering problems related to mass and energy balance and heat transfer
- Set up and solve simple calculations of energy production, with the use of e.g. practical programming tools
- To present results of calculations in an efficient way

At the end of the course the students should have gained skills to applying engineering methods to solve simple energy related problems.

This course is integrating practical programming tools into thermodynamics and energy technology. In other first semester courses, the students also use Matlab where applicable. To name few examples, the students use Matlab for analyzing measurement data and representing results in Physics lab classes. In Calculus students use Matlab for numerical methods to compute integrals and solve equations (using the bisection method). The tools (Matlab programming for engineering and scientific problem solving) are therefore taught in one course in the first semester and used in the courses taught parallelly. This can be related to the CDIO Standard 3 – Integrated Curriculum.

As seen from the above learning outcomes, the Energy course covers variety of subjects in programming and energy engineering and it has been a challenge to merge all these outcomes into a single 6 ECTS course as described in the following section.

Lessons learned

The course Energy has now been taught 3 times, in the autumn semesters 2020-2022. First two times the course was taught was under challenging circumstances due to to Covid-19 restrictions. The course in 2020 had the Matlab content integrated into the thermodynamic content from day one but the first two weeks were however more focused on getting the fundamentals of Matlab programming. Gradually, the Matlab content was built up and used for problem solving in thermodynamic exercises.

The students experience from the first round, as reported in the student teaching survey, was that students often found this quite overwhelming to be learning programming and thermodynamic simultaneously since for most of the students, both these topics were new to them. It was therefore decided, for the second round of the course Energy in 2021 to divide these topics more and focus on Matlab only for the first 4 weeks and teach thermodynamics and energy technology with Matlab integration for 8 weeks after that. This proved to be a successful change and was taken one step further by splitting the energy course into 4 weeks Matlab course and 8 weeks of Energy course with Matlab integration. This is summarized in Table 2 which shows how the course has developed over the three years period 2020-2022.

Table 2. Setup of the Energy and Matlab course

Autumn 2020	Autumn 2021	Autumn 2022
T-101-ORKA (6 ECTS)	T-101-ORKA (6 ECTS)	Two courses: T-101-MATL (2 ECTS) & T-102-ORKA (4 ECTS)
One course: Matlab programming, thermodynamics and energy technology integrated for 12 weeks	One course: Matlab programming for 4 weeks. Thermodynamics and energy technology with Matlab programming integrated for 8 weeks	Two courses: 1) Matlab programming for 4 weeks. 2) Thermodynamics and energy technology with Matlab programming integrated for 8 weeks

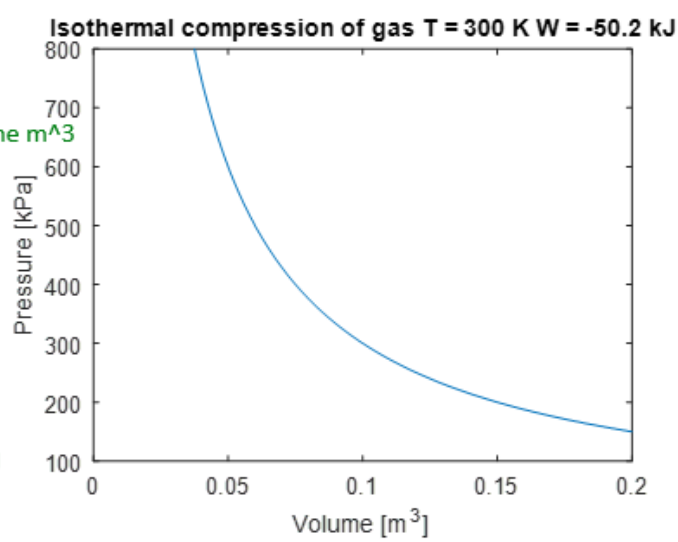
Course assessment and project examples

The course assessment consists of weekly homeworks and quizzes, midterm exams, group project work, activities in problem classes and a final exam. Figure 1 shows examples on how the basics of Matlab programming were used on a thermodynamic and an energy technology problem in the Energy course. The upper figure in Figure 1 shows Matlab code and a plot for an isothermal compression process of an ideal gas. The lower part of Figure 1 shows if-elseif-else statement in Matlab for using a range of velocity values for calculating wind turbine power and efficiency.

```
V1 = 0.2; % m^3
T = 300; % K
p1 = 150; % kPa
p2 = 800; % kPa
V2 = p1/p2*V1 % Final volume m^3
W = p1*V1*log(p1/p2) % kJ


V = linspace(V1,V2);
R = 8.31; % kJ/kg/K
n = p1*V1/R/T; % moles
p = n*R*T./V; % kPa


W2 = n*R*T*log(V2/V1) % kJ
plot(V,p)
xlabel('Volume [m^{3}]')
ylabel('Pressure [kPa]')
title(sprintf('Isothermal compression of ideal gas T = 300 K W = %.1f kJ',W))
```



```
clear, clc, close all
v = linspace(0,40,1000);
Pmax = 2000e3; % kW
rho = 1.2;
D = 90;
p = polyfit([4 15],[0 Pmax],1)
for i = 1:length(v)
    if v(i) < 4
        P(i) = 0;
        eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
    elseif v(i) >= 4 & v(i) < 15
        P(i) = polyval(p,v(i));
        eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
    elseif v(i) >= 15 & v(i) <= 30
        P(i) = Pmax;
        eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
    else
        P(i) = 0;
        eta(i) = P(i)/(0.5*rho*v(i)^3*D^2/4*pi);
    end
end

subplot(1,2,1)
plot(v,P)
xlabel('Wind speed [m/s]')
ylabel('Power [W]')
subplot(1,2,2)
plot(v,eta)
xlabel('Wind speed [m/s]')
ylabel(['Efficiency'])
```

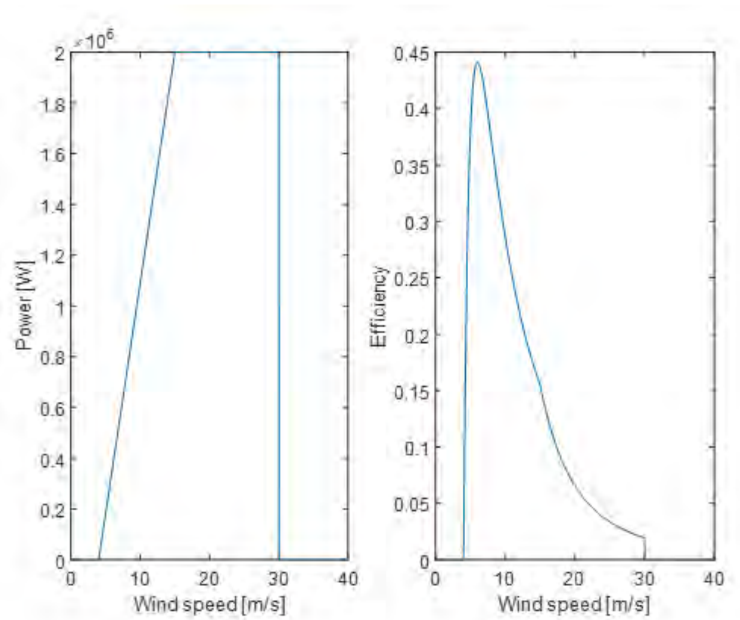


Figure 1. Examples of two problems students solved in the Energy course using Matlab.
Upper: Calculating and plotting an isothermal process of an ideal gas
Lower: Calculating and plotting wind turbine power and efficiency

Examples of larger group projects in the Energy course where Matlab was applied to analyze real world data and present the results in a video and/or report are:

- Estimating wind power potential on a specific site based on wind speed data and how well this power could fulfill the requirement of the use of that site (based on data from a nearby substation)
- Determining power production potential from overflow of an existing hydropower reservoir (Landsvirkjun, 2023). A preliminary design of the plant and to select an appropriate turbine type. Determine how much hydrogen can be produced using this additional electricity produced

These assignments from the Energy course are examples where students used Matlab as a tool to enable a successful solution of the problems they were given. This combines Integrated curriculum and Introduction to engineering which are two of the 12 CDIO standards (CDIO, 2023).

DISCUSSION

Curriculum change was made for the first-year engineering students where 2x6ECTS courses in Matlab programming and Thermodynamics were combined into one 6ECTS course called Energy. The lessons learned from the first two rounds the course was taught, was to prepare the students first in the basic principles of Matlab before energy related topics were introduced. Therefore, we have changed this into 2 new courses, a 2 ECTS course Programming in Matlab and 4 ECTS course Energy. Merging together thermodynamics and Matlab programming in a one course has been an interesting and a challenging process, especially under dynamic and limitating conditions due to Covid-19.

It turned out that integrating these two topics entirely may have been too large step for first-year students starting their university journey where most of them have little or no background in programming. Therefore it was decided to distinguish more between the two topics. In this development, we have however learned, that with 4 weeks of Matlab training the students get enough background to integrate their knowledge into other proceeding courses and work on real world problems. It is also important that Matlab is integrated systematically into the other first year courses to ensure continuity in the curriculum and the student use this useful tool that Matlab programming can be in their science and engineering subjects.

Integrating the curriculum according to the CDIO standards is an important part of the curriculum development at the Department of Engineering at RU and combining these two subjects, introduction to programming and thermodynamics is only one part of the overall CDIO implementation at the department.

In light of the current development related to tackle climate change by energy transition it is essential that all modern engineers have a solid basic understanding of the laws of thermodynamics and energy technology. Also, it is important that engineering students work from the beginning of their study on real life problems and use the tools that have been introduced to them (e.g. Matlab programming) to enable a successful solution to the problems and representation of the results.

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BIOGRAPHICAL INFORMATION

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BUILDING UP THE RELEVANCE IN ECONOMICS EDUCATION AND ASSESSING ITS EFFECT

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ABSTRACT

Even though economics is still mostly being taught in a traditional manner, there seems to be increasing emphasis on the role of concept relevance in better teaching. At the present, numerous teaching methods are being used in order to keep the coursework interesting as well as relevant. Be that as it may, game-based instruction or online teaching is more challenging to be used when teaching certain subjects than others. This paper proposes a novel teaching method which is a mixture of drama-based teaching, field survey, debating and online video discussions, the combination of which would promote the relevance of the subject being taught as it engages the students in the classroom. In this paper, we tailor a curriculum based on concrete and hands-on experience to promote collaborative learning and cultivate critical thinking. Furthermore, another goal of this study is to assess how students' learning styles respond to different teaching methods. We attempt to understand the interaction between teaching pedagogy and students' learning styles in order to improve economics education. The study follows a deductive reasoning approach based on data gathered through distribution of two questionnaires among students at an economics class in Feng Chi University; one before and one after the final test. According to the findings, our teaching design has the potential to increase the students' level of perceived relevance between what they learn in class and what they observe in real life.

KEYWORDS

pedagogy, interactive learning, subject relevance, economics teaching, Standard 8

MOTIVATION AND RESEARCH QUESTIONS

Economics is considered to be more abstract and theoretical among various disciplines of social science. It has been promoted for a long time that economics teaching needs to be adjusted and modified (Becker & Watts, 1996, 2001; Becker, 2003). Regrettably, traditional lecture format, popularly known as "*chalk and talk*" still dominates economics instruction. Majority of economics teaching still uses traditional lecture style, and consequently, widens the gap between teaching and learning types. As addressed by Hoyt & McGoldrick (2019) in their conclusion,

"*And lest we be accused of ignoring the elephant in the room, we leave you with the following: we must acknowledge that lecture is still the dominant pedagogic practice in economics, but is this in the best interest of our students and if so, how might we develop even more effective lecture methods?*"

To make the coursework relevant and interesting, various teaching approaches have been utilized in today's classrooms. However, courses like labor economics or economic law may face some challenges to be taught using popular game-based instructions or online learning. Therefore, how to design an economics curriculum with the aim of promoting the relevance of the subjects and engaging students for actively learning is a much-needed goal. In this study, we propose to combine multiple teaching methods including drama-based teaching, field survey, debates and popular media discussions, to engage the students by showing real world relevance of the subjects and making them more interesting.

We plan to conduct our teaching practice research in the course of "Human Resources Economics", which is an elective course at the Department of Economics, Feng Chia University. Feng Chia University adopts the CDIO initiative at the university level, regardless of the discipline. This course is on the application of economic principles in analyzing the labor market and allocation of human resources. The course covers a variety of subjects, including but not limited to labor force supply and demand, wage determination, labor market diversification and equality, and human capital. Moreover, the course also includes subject matters such as labor policies and labor law. The curriculum will build a bridge between the theories and real-world issues which would motivate students to engage more actively in the learning process.

As pointed out by Liang, Deng & Tao (2011), CDIO-based teaching method is a pedagogy which organically integrates teacher's research-based teaching and student's research-based studying together. This paper is a report of how we have adopted this method in an economics class. We expect our curriculum design to be capable of enhancing students' interest and improve their learning effectiveness. In particular, drama-based teaching or psychodrama is an innovative attempt in economics education. Drama-based pedagogy, which helps create an environment for focused inquiry and learning opportunities, is integrated into special topics. Role play provides an effective way to develop empathy in students and should help them learn through dramatic plays. Through said process, we believe that problem-solving and creative thinking abilities can be cultivated, which will enable students to deal with potential labor issues in the real world. As addressed in CDIO syllabus 3.0 (Malmqvist et al., 2019), living in an "accelerating" world, we intend to lead our students to reach the mission:

"*It must empower them to be leaders of innovation, to not only be able to adapt to a changing world, but also to change it*."

To access the skills acquired by teamwork-based projects, multiple evaluation methods were customized including the peer assessment and the logbook assessment techniques. Peer assessment helps students pay more attention to peer performance and give feedback constructively (Huet et al. 2008). This study also attempts to assess how students' learning styles respond to different teaching methods. Charkins, O'Toolem & Wetzel (1985), point out that the discrepancy between teaching styles and students' learning styles leads to a poor learning performance. Moreover, with said discrepancies, students tend to hold negative opinion toward economics. Borg & Shapiro (1996) also encourage instructors to apply a more diverse teaching and assessment strategy in response to various learning styles. Ziegert (2000) and Lage et al. (2000) also share the same view in their later research. Jensen & Owen (2001) analyze the larger scale sample and find that instructors' learning skills excise a significant impact on their choice of economics as a major in the future. Other studies also find a clear connection between students learning styles and their academic achievement, arguing that certain learning styles are more effective. More recently, Zhang (2016) concludes that diverse teaching pedagogy would bridge the learning gap among students with different learning types.

The goal of this project is to bridge the gap between students and professional knowledge by making the coursework relevant and interesting. Cooperative learning and team work are emphasized inside and outside the classroom. In line with our diverse teaching models, multiple assessment methods are applied to explore student learning outcomes. Together with a traditional written test, students' performance on drama plays and debates as well as course-embedded assignments and reflections, assist in interpreting students' learning achievements. We collect the data based on pre-test and post-test surveys to address our first research question.

RQ1: Will our curriculum design and practice enhance students' learning motivation and interests?

Our second research question is:

RQ2: will students with heterogeneous learning styles respond differently to our diverse teaching methods.

One shoe doesn't fit everyone's feet and it can be similar inside the classroom. We plan to explore the disparity among different learning styles in terms of preferences and learning outcomes. In the face of changing student body and their learning styles, how to evolve and adapt teaching strategies to accommodate students' learning styles is crucial. Through our curriculum design, we intent to evaluate how students respond to various teaching methods. With our results, we hope to find a clearer guidance for connecting students' learning styles and different teaching practices.

COURSE DESIGN AND ASSESSMENT METHOD

Using human resources economics as the subject matter, the experiment endeavors to close the gap between the theories covered in class and the realities of the outside world. We do so by employing group discussions and increasing the interactive aspect of the coursework. The class commences with gathering personal information on the students' and their families' employment status and conditions as well as their demographics. Consequently, the corresponding teaching method will be devised and employed. It includes group discussions on policy debates and current affairs.

Drama-based teaching, AKA psychodrama is a novel approach to teaching, rarely used when teaching economics. It adopts social drama combined with some psychodrama techniques. As a result, students will become more involved in the subject-matter. Consequently, they are expected to suggest solutions for the problems under discussion. The main design of the method is depicted in Figure 1:

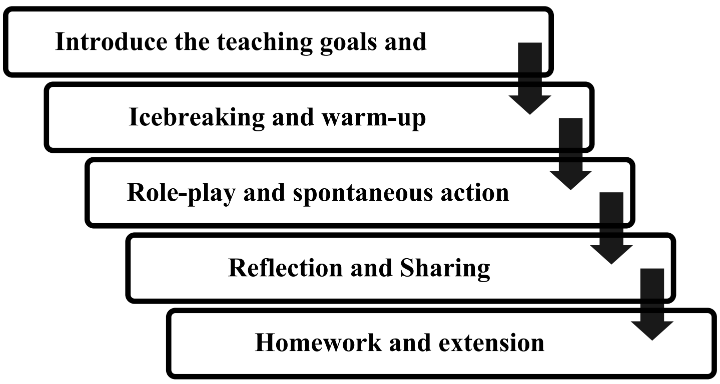

Figure 1. Framework of drama-based teaching

As it is shown in the Figure 1, drama-based teaching consists of five stages. First, the goals and objectives of the session will be explained to the students. Second, the instructor will work with the students to develop the goals and set the stage for the main act. Third, the students will act out the designed situation. Fourth, students will share their feedback on the drama in a group discussion. Fifth, the students may be assigned some exercises to deepen their understanding of the subject.

During and after the drama, the instructor (director) may ask the actor to change roles, adopt the character of another person, or pause to reflect on another character's behavior. These exercises may help a participant better understand the role of others, as well as alternative ways to face the same issue.

The third stage is in fact the main stage of the process. It may involve the use of characters and sculptures. The instructor will act as the director and set the roles. The plot shall continue in a three-act set. First, the characters and their roles are introduced. Second, the conflicts and issues are shown. Third, solutions to said issues are presented. This process allows the students to creatively and carefully account for different trade-offs and constraints when faced with economic decision-making. Moreover, the tools commonly used in psychodrama are also used in this type of teaching. This in turn will allow the students to take on different roles and take turns during discussions. Said tools include colored and patterned cushions, cloth strips, and cloth pieces. Finally, the students get to share their thoughts on the course through group discussions. Moreover, they shall complement their learning process via after class exercises.

We employed a drama-based teaching method with two plays. As the semester commenced some labor market indicators were introduced to the students. The data (based on the dynamics of the Taiwanese economy) were complemented with a rigorous fact check conducted by the students. Class discussion was a common practice in this course. This rescues the students from gruesome nonstop lectures. The discussions were followed by an Oregon style debate with five people on each side. Moreover, in another unit the students were asked to prepare a 12-15 minute performance with the objective of answering the following questions.

1. Why are there different payment methods in different industries and occupations?
2. What are the advantages and disadvantages of the salary system being portrayed in the performance?
3. How can employers increase employees' work incentives?

Not only the instructor, but also the students were involved in the grading of the performances. This peer-evaluation form is effective in ensuring the students' focus and attention to the performances' key aspects. Through follow-up analyses, one can observe the teaching effectiveness and find the best corresponding strategy suitable for the students' learning style of the students.

DATA AND OBSERVATIONS

For the purposes of this study, an undergraduate class, human resources economics, at Feng Chia University, has been put under observation. Said class has been managed differently, applying a drama-based teaching method. Moreover, the students' performance was recorded. In addition to that, students' perception of the method has been observed via distribution of a questionnaire in two rounds, one before their final test and one after. In this way, their performance could be observed relative to their perception of the new teaching method. Finally, the students were divided based on their learning method as well. The classroom consisted of 36 students.

The purpose of this study is to evaluate the effect of drama-based and subject relevance teaching on the students' learning outcome. We do so by assessing their performance before and after the tests divided by the students' learning styles. The learning styles are categorized based on the work of Kolb (1985). David Kolb in his influential work, experiential learning, suggests four learning styles; accommodating, diverging, converging, and assimilating. The accommodating learning style consists of concrete experience. Moreover, the diverging style includes reflective observations. Furthermore, the assimilating style consists of the students' abstract conceptualization. Finally, there is the assimilating learning style which includes students' active experimentation. In other words, Kolb's four learning styles comprise the acts of feeling, watching, thinking, and doing. His categorization is depicted in the following figure.

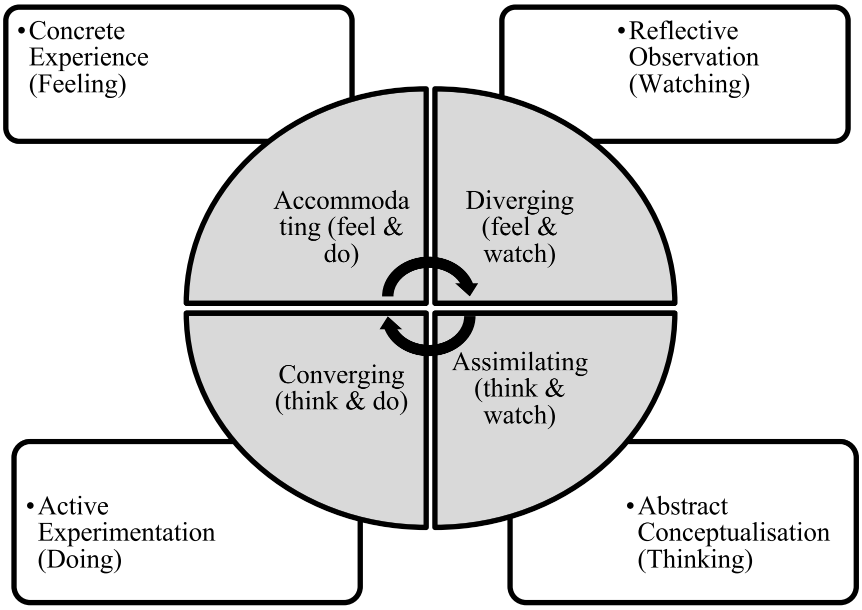

Figure 2. Kolb's learning styles (1985)

Table 1 reports the distribution of the participants categorized by their method preference as well as their learning style. The students were to provide their preferences among seven teaching method; drama-based, field survey, in-class discussion, debates, traditional lectures, and in-class assignment. As the numbers indicate, among the students, highest preference was for in-class discussions (20.31%). After that, lectures (18.75%), drama-based teaching (14.06%), and field surveys and debates (12.5%) had the highest preferences. The least preferred method was for in-class assignments. In terms of their learning style, the highest portion of the students was diverging (41.03%). Afterwards, there was the accommodating students (30.77%), followed by assimilating (17.95%) and converging (10.26%).

Among the students with a diverging style, most (24.44%) preferred lecture method and the lowest portion (8.89%) preferred debates and field surveys. In case of the students with an accommodating learning style, the highest share had a preference for in class discussions (20.45%) while the lowest share belonged to online videos (9.09%). Moreover, among the students with an assimilating learning style, the highest preference was for in class discussions and the lowest share was for debates, lectures, and in-class assignments. Finally, in case of students with a converging learning style, the highest share belonged to the discussions and debates (22.22%) while the other five methods had the same share (11.11%).

Table 1. Students' learning style and teaching method preference

Learning style \ Method preference	Drama-based teaching	Field survey	In-class discussion	Debate	Lecture in class	Online video	In-class Assignment	**Total**
Diverging	11.11%	8.89%	20.00%	8.89%	24.44%	15.56%	11.11%	41.03%
Accommodating	13.64%	15.91%	20.45%	11.36%	18.18%	9.09%	11.36%	30.77%
Converging	11.11%	11.11%	22.22%	22.22%	11.11%	11.11%	11.11%	10.26%
Assimilating	18.18%	18.18%	22.73%	9.09%	9.09%	13.64%	9.09%	17.95%
Total	14.06%	12.50%	20.31%	12.50%	18.75%	11.72%	10.16%	100.00 %

RESULTS

Table 2 reports the students' average performance grouped by their learning style. It includes their coursework average, their midterm report average, as well as their final exam average. The performances of coursework were evaluated in a more encouraging way, so the grades obtained from coursework are higher than those from more classical-style evaluations (midterm and finals). According to the findings, the worst performance for coursework, midterms and the finals all belonged to those with a converging learning style. Interestingly, the best performance in all three categories belonged to the students with an accommodating learning style. In all four styles, the student's midterm performance was worse than their coursework and their performance in the finals was worse than their midterms and coursework.

Table 2. Students' learning styles and their performance (out of 100)

Learning style	Total (%)	Coursework	Midterm report	Final exam
Diverging	41.03%	88.06	81.38	70.60
Accommodating	30.77%	88.92	86.08	74.67
Converging	10.26%	69.75	69.00	66.67
Assimilating	17.95%	87.86	83.57	68.57

Before the semester commenced, the students were asked to fill in a 10-question questionnaire. After the semester ended, they were asked to fill in the same questionnaire once more. It was designed to examine their perception with regards to economics as subject, its relevance to the real world, as well as their attitude towards learning in general. The ten questions are as follows.

Table 3. Survey questions for pre and post test

1. I like to think about economic issues
2. Learning economics brings me a lot of sense of accomplishment
3. I think economics is an interesting course
4. I can relate economic concept to situations that might apply in daily life
5. I think economics is very theoretical and difficult to understand
6. Economics is less practical compared to other business subjects
7. I often discuss class content or homework with my classmates
8. I like to work independently
9. If I have questions, I will ask my classmates for help
10. I think that the opinions expressed by my classmates in class are very valuable to me

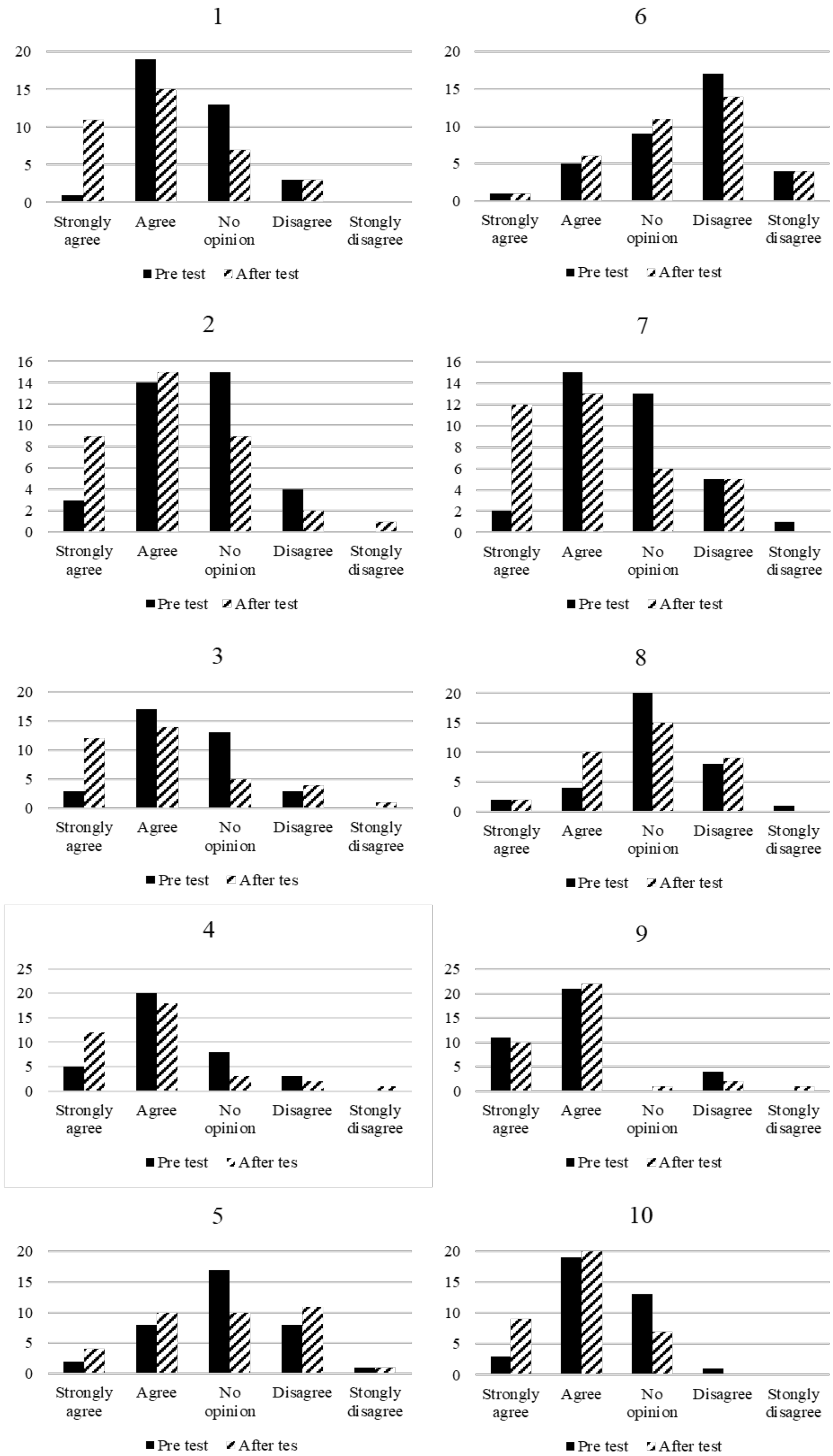

Figure 3. Students' perception of education and economics before and after tests

Figure 3 depicts the distribution of the students' responses to each question before and after their finals. According to the findings, the number of those who strongly liked to think about economic issues increased substantially after test relative to pre-test. Moreover, the findings indicate a decrease in the number of those not having an opinion about the second question in favor of agreeing and strongly agreeing with it. As for those thinking economics to be an interesting subject, the number of those who strongly agree with the matter was much higher after test relative to pre-test. Furthermore, the findings suggest that more students strongly agreed with the argument that economic concepts are relatable to daily life matters after test than pre-test. However, the findings also suggest an increase in the number of students who strongly think economics to be very theoretical after test than pre-test.

Both before and after the test, more students disagreed with the claim that economics is less practical than other business subjects. Moreover, the figures suggest a slight increase in the number of students who agree and those who do not have an opinion on the matter after test than pre-test. As for the last four questions which cover the students' perception on overall education, the numbers indicate that substantially more students strongly agree that they discuss the class content with their classmates after test than pre-test. Moreover, most of students both pre-test and after test showed no opinion about their independent learning behavior. However, the number of those who agreed increased substantially after test while the number of those with no opinion decreased after test. Furthermore, almost all the students claimed that they would seek their classmates' help in answering their questions. Finally, the findings indicate that most of the students agreed that their classmates' opinions had meaningful value. Moreover, the number of those who strongly agree to said statement was substantially higher after test than pre-test.

DISCUSSION

Among the social science disciplines, economics has always been considered more abstract and too theoretical, making it distant from reality. while novel teaching styles are increasingly gaining popularity, the majority of economics classes are still being taught in the traditional way. This study was an examination of how subject relevance teaching can be applied when teaching a class on labor economics. It was done so with the hope of closing the gap between theories taught in class and the realities of the outside world. In particular, drama-based teaching is among the recent innovations in pedagogy. In short, it consists of several short plays that are designed and performed by the students and are based on the subject matter being taught, in this case labor economics and human resources. Moreover, the students were given a short questionnaire to record their perceptions with regards to economics as a subject as well as their view on more general aspects of the learning process. Same questionnaire was distributed once in the beginning of the semester and once in the end. It also recorded the students' teaching method preferences and their learning style.

Overall, the study proves these new methods of teaching to be a success in closing the gap between theories taught in class and the real life issues the students observe outside the classroom. Moreover, students showed to be more active, and got more involved in the learning process. They turned from passive listeners of one-sided lectures to active participants of group discussions. Furthermore, the study suggests that the classrooms are heterogenous entities, comprising of students with different learning styles. Getting them to work together in groups could certainly improve their learning curve. Be that as it may, the findings indicate that there is no single shoe that fits all feet. The best course of action would be to combine different methods so the class becomes more accommodating to different learning styles and responding to the needs of different students.

Finally, there are several aspects of the topic that were outside the boundaries of this paper and could be further studied by interested scholars in the future. First, the drama-based teaching method could be applied to other subjects than labor economics and then the results can be compared with the present study. Second, besides data on the labor market, in a future study more practical issues about human resources management can be included in the curriculum. Finally, we do not assess whether students' performance can be enhanced if we apply different teaching model on students with different learning styles in this paper, and this link can be studied in the future.

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BIOGRAPHICAL INFORMATION

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VUCA AND RESILIENCE IN ENGINEERING EDUCATION – LESSONS LEARNED

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ABSTRACT

As future system designers and decision-makers, engineering students should be trained to anticipate and navigate the unknown. These days, engineers often operate in professional, social and societal environments characterized by volatility, uncertainty, complexity and ambiguity (VUCA). Therefore, besides traditional engineering skills, educational programs must also provide students with future skills that are needed to address VUCA situations. This requires the competence and vision to design and manage systems that are resilient to unexpected, unstable and drastic events. This paper presents, compares and discusses teaching and learning activities addressing VUCA and resilience, occurring at different curriculum levels. Key lessons include the need to integrate VUCA and resilience training in a progressive manner, from freshman level to that of professional engineers. Recommendations are made for how engineering programs can better prepare graduates through the use of effective learning methods that are aligned with specific learning outcomes. Elements to extend an educational framework are suggested with curriculum integration based on examples of authentic experiences.

KEYWORDS

VUCA, Resilience, Teaching and Learning, Future Skills, Engineering Education, CDIO Standards: 1, 2, 3, 7, 8, 9, 11.

INTRODUCTION

Volatility, uncertainty, complexity and ambiguity (VUCA) characterize current and future challenges that engineers must face in their work, with "the shift from the traditional and simple situation of known knowns to the chaotic VUCA situation of the unknown unknowns" (Kamp, 2020, p. 13). Professional, social and societal environments, as the contexts and situations engineering teams have to operate within, as systems they design, are also strongly characterized by so-called VUCA characteristics. Raja (2021) makes a case for the relevance of VUCA in today's world, and further argues for a focus on leadership development as a way to deal with the disruptions associated with VUCA. The concept of VUCA, the origins of which can be traced back to the US Army (Clements, 2017), also has relevance in understanding the lack of stability and rapid changes witnessed in the business world (Lawrence, 2013). VUCA results in challenges for practitioners and leaders (Mueller, 2021). Resilience describes the ability, not only to quickly recover from and to respond to such events, but also to build adaptive capacity by learning from failure (National Research Council, 2012; Walker, 2020). Accordingly, resilience is crucial to address VUCA situations and characteristics (Rockley, 2022).

Therefore, besides traditional engineering skills, educational programs must also provide students and future leaders with the skills needed to face and tackle VUCA situations. Learning outcomes should echo the vision and competence to design systems that are resilient to utterly unstable and drastic events (Chester & Allenby, 2019; Clements, 2017; Martin et al., 2022). Implied are not only technical systems, but also engineering teams and their leaders. Those events may be society driven or may be a consequence of the inevitable more unstable and dynamic environment – like black swans appearing suddenly in the misty future. Future engineering practitioners and leaders should be trained on strategies which can help develop their ability to prepare for VUCA and to enhance resilience at different levels (Rimita et al., 2020), as resilience is a key competence and characteristic in dealing with the 'new normal' (Raja, 2021).

But how should resilience training in engineering education best be developed in order to, in the future, quickly recover systems and the teams that build them? This paper argues that VUCA and resilience training are connected and, as a premise, there is a need to reinforce students' abilities to work in VUCA situations. Drawing on four case studies from four countries, this paper compares and discusses teaching and learning (T&L) activities at different curriculum levels in higher educational institutions, and the extent to which they meet VUCA and resilience outcomes, mainly focusing on engineering education. With reference to both the diverse, interactive T&L methods and the aligned learning outcomes, this comparison enables insights into the challenges and opportunities of the respective approaches. The cases describe events where teams of engineering students have to tackle VUCA situations in real time early in their engineering curriculum in Iceland and France, students in their MSc program having to work on resilience strategies for diverse systems in Germany, and finally, students acquiring VUCA capabilities in the context of postgraduate and professional training in South Africa. The focus is on which T&L approaches are suitable to enable engineering students to design resilient systems in the context of a VUCA environment, and what competencies and learning outcomes are necessary to achieve this. Based on the experience of offering these different courses, the four approaches are analyzed in terms of similarities and differences, in order to integrate essentials within an educational framework for teaching resilience at different levels, and to examine how they are related to the CDIO educational framework. These elements are suggested to facilitate the rapid acquisition of VUCA and resilience skills.

TEACHING AND LEARNING APPROACHES

It is critical that 21st century T&L approaches include not only teaching the VUCA concept to students, but also assisting them to be well equipped for life in a VUCA world (Clements, 2017). This will allow individuals to develop intrapersonal capabilities, such as self-leadership, lifelong learning or resilience, but will also enable them to design and develop systems that are resilient in a VUCA environment. A VUCA context is quite unstable and unlikely to be deterministic. On the one hand, knowledge and know-how of dealing with complexity is inherent to most engineering programs, as required by accreditation bodies (e.g. ENAEE, ABET), where the learning process should enable graduates to demonstrate the ability to solve complex problems, so as to design, analyze and develop complex engineering products, processes and systems. On the other hand, VUCA environment training is more in the scope of competencies, is situation-oriented and relies on knowledge, skills and attitudes. Resilience, as the ability to adapt, withstand and recover within a VUCA environment, inherently requires system thinking (Mayar et al., 2022). Therefore, T&L approaches for a family of situations are needed, which foster competencies at higher complexity levels, such as systems or anticipatory thinking. Various T&L approaches in the context of active learning are adequate to meet VUCA and resilience development, e.g. those ranging from problem- and project-based learning, to experiential learning or professional work-based learning (Ban et al., 2015; Fazey, 2010). This section presents four case studies from different countries, and at different curriculum levels.

The four examples are in line with the spirit of the CDIO initiative. In particular, the ability to deal with resilience of a product, process and system may be considered as implicit in the CDIO Standard 1, which involves the context in engineering education. Moreover, the learning approaches in the four examples are all more or less based on experiential learning, which is explicitly referred to in CDIO Standard 8 as a core function of active learning. Experiential learning is also mentioned in CDIO Standard 7, which motivates for integration of VUCA learning experiences with the learning of disciplinary knowledge, and emphasizes the impact of these experiences.

Example 1: Disaster Days in Iceland (freshman engineer year)

The “Disaster Days” initiative at Reykjavik University was designed as an intensive two-day event that is mandatory for all engineering students early in their first semester in the program (e.g. CDIO Introduction to Engineering). The learning outcomes of the event were first to introduce the students to some unexpected, ambiguous situation that they had to confront in real time and second to realize the value of diversity within the teams. At the beginning of the event, students were briefly introduced to a disaster that was just about to unfold. Most of the information given was vague and ambiguous, and the event unraveled in the subsequent hours. In this way, the intention was to mimic a real time VUCA-like scenario that the students had to tackle. Typically, about 200 students took the course and worked in approximately forty teams of four to six students. Each team was asked to come up with recommendations to the local government on how to deal with the situation. The events were designed in such a way that the students had to analyze the situation and do some back-of-the-envelope calculations. Because the assignments were ill-posed, each team had to improvise in defining their approach. Events in the past have included a threatening volcanic eruption near the city of Reykjavik, an imminent tsunami, that Iceland has to host the Eurovision Song Contest with only a few days’ notice, and a severe pandemic (fall 2019). All the events were realistic and although unlikely to happen, could still have been possible. Faculty members were assigned to teams as facilitators, but the teams mostly worked on their own.

Introducing students to VUCA-like situations early on in their studies may provide them with some skills when confronted with ill-posed problems later in the progression of their degrees. Student feedback indicated that teamwork affected them the most and was considered a valuable experience. Teaming also opened doors to social networking. By far, most of the students liked the event because it was so different to what they were used to in their traditional courses of study, and enabled them to think 'outside the box', as some mentioned. A few students commented that the task given was too ambiguous, but most appreciated that it was so open. A detailed description of Disaster Days can be found in Audunsson et al. (2018).

Example 2: Man Overboard in France (sophomore engineer year)

In the context of a European project (www.dahoyproject.eu) at IMT Atlantique, an intensive one-week course for engineering sophomore-year students has been operated (Rouvrais et al., 2019). In real and authentic situations during two and a half days of the week, students are required to act in Man Overboard (MOB) sessions with progressive VUCA criticality levels. The learning is experienced on a sailing boat with around sixteen students inexperienced in the sea environment. Formally, the course permits students to develop and reinforce seven learner decision competencies, each in the context of VUCA characteristics: recognize and qualify; analyze; make a judgment; face the unknown; organize and implement actions; take responsibilities; and learn from experience. While one group is acting, the others observe. Up to fourteen incremental VUCA scenarios are used for MOB, all repeated twice for a team. In each scenario, after a first unexpected and unknown event, students have to define their own rescue procedure based on a short return on experience with the other observer group (reflective practice). A similar event is then repeated to implement the procedure, sometimes with less efficiency due to their procedural rules and new unknown external factors. The concept of meta-rules is thus presented to students after the sea experiences, as rules governing a set of lower-level rules.

The optional course is located in the middle of a curriculum when students are already aware of complex situations they may have to handle as engineers, but still have room to discover new characteristics inherent to VUCA situations. Learning assessment is formative, aligned with the seven learning outcomes. Attitudes and emotional competencies linked to teamwork and leadership are solicited in action but are not assessed (e.g. cases of leadership friction, empathy, anxiety). An interpersonal characteristic was added to extend the VUCA model. In triggering judgment and decision-making skills, this course permits students to develop higher confidence in their ability to grasp VUCA situations, and allowed them to adapt dynamically to unexpected circumstances and unstable contexts. Nevertheless, the VUCA precise characteristics of a situation took time to appropriate in a week only and the letter semantics tend to also be ambiguous. Description of some student feedback can be found in Rouvrais and Gaultier Le Bris (2018).

Example 3: Resilient System Design in Germany (senior engineer year)

As an elective master's course, the seminar "Resilience and socio-technical systems" takes place annually over a period of five months and targets engineering students from civil, environmental and industrial engineering at RWTH Aachen University. After completing the course, students should not only have sound knowledge and understanding of the concept of resilience, but should also be able to apply resilience and system thinking to different contexts and be able to analyze and evaluate existing crisis management approaches with regard to resilience. The teaching approach consists of several elements in the context of active learning, such as problem- and case-based learning as well as collaborative learning, and is described in detail in Winkens and Leicht-Scholten (2022). By working in groups during the semester, students elaborate a real-world case study on socio-technical systems in reference to resilient system design. The design of the case has been varied in the last years. In one semester, students were given a case on COVID-19, in which they had to take the perspective of a resilience consultant to advise local politics. In another semester, students were able to choose their own case. In both instances, the resilient system design did not only include technical artifacts, instead students had to critically reflect on failures, possible future state, system boundaries and interactions as well as on different stakeholder perspectives.

Moreover, several unknowns were given in the context of which the students had to conduct a scenario analysis. By dealing with an ill-defined problem, students should acquire VUCA-related competencies by learning to deal with uncertainty and complexity, and learning from failure, and should also enhance their anticipatory and system thinking competencies. The course results showed that students developed, in particular, the competencies with higher levels of complexity (e.g. analyze, evaluate, create) during the course. At the same time, these competencies were hardly pronounced before the course. Evaluations and feedback sessions with the students revealed that the task was challenging for them, as they had no previous exposure to resilience or VUCA contexts.

Example 4: Leadership Training in South Africa (postgrads and professionals)

The context in this fourth case is that of a leadership course taught to postgraduate adult learners in the Business School of the University of KwaZulu-Natal (UKZN). The majority of the participants are working students based in the public and private sectors in South Africa. The students emanate from diverse educational backgrounds and hence also workplaces, including the engineering sector. As an academic teaching leadership to adult learners in the Business School, it is critical to draw on the diverse, rich experience that the students bring with them to the classroom. The classes are highly interactive with an emphasis on individual and collective learning, solidified by student-centered approaches, facilitation, and experiential learning. As Business School students possess different qualifications, engineering being among these, it is not possible in most cases to say whether they have had formal VUCA or resilience training in their previous qualifications. However, the students do have valuable life and work experience, which may have already exposed them to VUCA situations and the importance of resilience. The course offered by the Business School thus provides a formal language and skills to assist these diverse students in their leadership development.

There are many challenges facing South Africa, and thus it is crucial that leaders and managers are equipped with the necessary skills to navigate the complexity faced in their workplaces. This is in line with principles of adult learning, where it is argued that these students should learn subjects relevant to their work and personal lives. The classes at the Business School commence with an introduction to VUCA, which inevitably most students have never heard of, but most are impressed with. Time is taken to allow the students to examine the leadership challenges that they face within the context of constant change, and to be able to develop a mindset which is not resistant to change, but rather embraces it and is proactive, thus enabling students to rapidly respond to disruptions. Herein, students gain rich insights as they get to hear about the experiences of fellow students in their work and personal contexts. Many students in the course evaluations often highlight the value of 'realizing that they are not the only ones feeling that way'. The VUCA context then paves the way to allow learners to reflect on what leadership entails, especially in light of the view that their leadership roles should not be focused on being about a position or title, but should rather be understood as an influential relationship amongst leaders and followers who intend real changes. An understanding of VUCA helps the students to understand how they, as leaders and managers, need to have the skills to operate in dynamic, non-linear contexts, where there are high levels of unpredictability (Cartier, 2022). They are able to gain awareness of how they need to conduct themselves in their leadership roles, embrace change, and become adaptable and resilient to deal with the constant changes that define the complex systems that they form part of (Folan, 2021). Emphasis is also placed on gaining self-awareness and personal mastery, but also being able to lead a team and deal with organizational change and culture.

Overview

Table 1 provides an overview of the four T&L examples, as well as their main pedagogical aspects. Thereafter, Table 2 outlines the intended learning outcomes of each example. Based on the outlines provided in Tables 1 and 2, the following section discusses similarities, differences as well as challenges and opportunities of progressive reinforcement of students' skills in the scope of VUCA and resilience.

Table 1. Overview of Four Examples for Teaching VUCA Characteristics

Example	**#1 Disaster Days in Iceland** (Reykjavik University)	**#2 Man Over Board in France** (IMT Atlantique)	**#3 Resilient System Design in Germany** (RWTH Aachen University)	**#4 Leadership Training in South Africa** (UKZN)
Students	First year engineering	Bachelor's & Master's + Erasmus	Master's	Postgraduates
Fields of Study	All students in engineering	IT Engineering	Civil, Environmental, Industrial Engineering	Leadership (diverse student body, including engineers)
Size	200 students, in groups of 5	16 students, in groups of 4	25 students, in groups of 5	15–20 students, in groups of 4 to 5
Part of Curriculum	Mandatory	Elective	Elective	Mandatory
ECTS	1	2	4	6 (equivalent)
Interval / Duration	2 days in the fourth week of semester	Full week between 2 semesters	1 Semester	Block release (2 weeks)
T&L Approach	Experiential learning; PBL; Open ended task	Experiential learning; Peer-learning with reflective debriefings	PBL; Case-based learning; Peer-learning	Experiential learning; Adult learning; Collective learning
Assessment	Team presentations	VUCA field practice; Peer-assessment	Group presentations and reports; Reflective Diaries; Peer-assessment	Reflective assignments
Content/Keywords	VUCA; teamwork; quick decision by a team; multiple disruptions	VUCA progressive scenarios; teamwork; leadership; snap decision	VUCA; resilience assessment methods; scenario planning; system thinking; disasters, learning from failure	VUCA; multiple disruptions; change; leadership; self-awareness; personal mastery; system thinking; team leadership; organizational culture

Table 2. Learning Outcomes and Experience of the Four Examples discussed

Course	**Learning Outcomes and Experience**
#1 Disaster Days in Iceland (Reykjavik University) 1 ECTS	After completing the course, students are able to: - experience teamwork and understand the importance of cooperation and diversity in a group; - are introduced to diverse ways in presenting solutions; - experience a situation where decisions and planning are based on uncertain information.
#2 Man Over Board in France (IMT Atlantique) 2 ECTS	After completing the course, students are able to: - recognize and qualify the VUCA characteristics of situations; - analyze VUCA situations; - make judgment in VUCA situations and face VUCA characteristics of situations; - organize and implement actions in VUCA situations; - take responsibilities of the decision process in VUCA situations; - learn from VUCA experiences.
#3 Resilient System Design in Germany	After completing the course, students are able to: - develop local resilience-based approaches with regard to the COVID-19 pandemic; - reflect on resilience-oriented approaches and ways of thinking in their future work as engineers. Moreover, they reflect on the relevance of resilience-oriented approaches to local and global crises;

(RWTH Aachen University) 4 ECTS	- analyze different scenarios with regard to their resilience effects. They assess existing crisis management approaches regarding their resilience potential; - apply resilience-oriented approaches to practice-related decisions; - outline, compare and contrast different interdisciplinary discourses regarding the concept of resilience. They understand the relevance of crises in the 21st century; - define resilience with its various conceptions.
#4 Leadership Training in South Africa (UKZN) 6 ECTS	After completing the course, students are able to: - develop leadership capabilities to assist in navigating through disruptive times; - develop self-awareness, personal mastery, team leadership, and gain insights into organizational culture and organizational change; - recognize how the inner aspects of leadership play a role in how they lead self and others; - analyze, reflect on, compare and critique leadership approaches and challenges in diverse work contexts; - develop critical perspectives on leadership theories and practices, and understand the application thereof to their professional and personal lives, especially in a VUCA world.

DISCUSSION

Challenges and Opportunities

A comparative analysis of the presented T&L approaches resulted in the identification of both similarities and differences. A VUCA context is based on high levels of 'unknown unknowns' and students thus need the opportunity to learn to deal with this uncertainty. Accordingly, they need to be actively engaged on problems or cases which are ill-defined, but which also represent real-world problems (e.g. volcanic eruption, men over board, pandemic or leadership challenges). All presented approaches include active learning by providing a learning environment that enables engineering students to reflectively work on topics of resilience or VUCA. Notably, in all courses, students work collaboratively and are thereby gaining communication and teamwork skills. The students also develop decision-making and crisis-management skills, which are valuable in navigating the VUCA world. The assessment methods include group presentations and reports, and in some cases, peer-assessment and reflective tasks. The analysis of the four T&L approaches also illustrates the responsibility of academics to teach students to be well-equipped for an uncertain future, and not only to impart content knowledge in a way which may create a potentially false impression of a simple rather than VUCA world. The various approaches also demonstrate how to factor in system thinking and complexity into the curriculum.

Despite the similarities noted above, the four approaches also have differences. First there is the structural difference, which means that the courses are located at different stages in the curricula. Second, there are large classes with around 200 students in some locations, as well as very small classes in others. Furthermore, the courses can be distinguished as either elective or obligatory courses. There appears to be value in incorporating VUCA and resilience topics throughout the curriculum. Early exposure in the curriculum to these valuable concepts may have a wide-spread significant impact on the students' abilities to navigate complexity. A focus on postgraduates and working students also has tremendous value, by incorporating their work and real-world experience. In terms of the complexity level of learning outcomes apparent in each of the four courses, example 1 is closer to "Remembering" level (have experienced), example 2 at "Analyzing" level, example 3 more at "Creating" level (develop), and example 4 closer to "Evaluating" (critique and challenge).

Example 1 takes place very early in the first semester. In contrast, examples 3 and 4 refer to either master's students or postgraduates, whereas example 2 targets both bachelor and master's students. The timing at which students (can) take the courses has an impact on student outcomes, as evaluations or feedback sessions with students have shown. For example, the mandatory course in example 1 showed that students value thinking and working out of the box so early on in their degrees. They also appreciated the teamwork experience.

These experiences can be valuable for students' further study progress by being introduced to VUCA contexts quite early and therefore, promoting the development of skills very early on to enable them to deal with complexity and uncertainty in their roles as future engineers. Example 2 shows how a course can benefit from being located in the middle of the curriculum, based on students' prior knowledge and awareness of complex situations. However, this is only suitable if the students do indeed have prior knowledge and experiences in VUCA environments, which is not always the case. Students took long time to clarify the semantic of the four VUCA dimensions. In contrast, in the elective master's course in example 3, students noted that they had significant problems with the level of uncertainty and complexity, because they had not learned to deal with it before. Furthermore, they had hardly any prior knowledge about resilience-related issues. Finally, this is also illustrated by the fourth example, in which postgraduates initially reflect on their roles as leaders and what leadership entails in an uncertain and ambiguous environment. Leaders who are able to navigate VUCA are critical, given the multiple disruptions that are experienced, and how difficult it is to predict the future (Cole, 2022). The four – partly strongly contrasting – examples illustrate the relevance for a holistic and systematic curriculum approach, as represented by the CDIO educational framework.

VUCA situations can also now be a context of engineering education through which skills are taught, practiced and developed, and where students are exposed progressively from well-defined problems to ill-defined VUCA problems and situations.

Educational Framework Integration

The CDIO syllabus evolves, and revisions are implemented in tandem with changes in society and the expected working environment of future engineers. In the recent update of the syllabus, Malmqvist et al. (2022) stated that there are mainly three external drivers that motivated the changes in the most recent upgrade: sustainability, digitalization, and acceleration. Both VUCA and resilience as discussed in this paper are in the realm of acceleration and one may argue that resilience is an implicit factor in sustainability. Targeted teaching of resilience can contribute to sustainable development (Fazey, 2010).

Thus, specific learning outcomes may help to ensure that students acquire the appropriate foundation for their future to become lifelong learners, a foundation which includes VUCA capabilities and resilience. In the recent 3.0 version of the CDIO syllabus in particular, some categories and topics address resilience-related aspects (Winkens et al., 2023, under review), such as 2.3.2 on emergence and interactions of systems, or 4.1.6 on visions of the future. Moreover, the CDIO syllabus proposes learning outcomes such as initiative and willingness to make decisions in the face of uncertainty (LO 2.4.1) and analysis with uncertainty (LO 2.1.4), uncertainty being just one facet of VUCA situations. Table 2 presents further learning outcomes, for instance, analysis, team leadership, and reflective skills as VUCA-abilities and system resilience.

VUCA and resilience outcomes are transversal to curricula. Related competencies include skills and attributes developed by students when they are placed in VUCA contexts. As stated in the CDIO Integrated Curriculum Standard, "the integration of skills and multidisciplinary connections are to be made, for example, by mapping the specified learning outcomes to courses and co-curricular activities that make up the curriculum" (Malmqvist et al., 2020). To meet dedicated learning outcomes, within the context of simple problems to progressive high VUCA contexts, T&L activities may reach individuals, organizations, and communities, as the sociotechnical systems to be built. The CDIO Integrated Learning Experiences Standard prompts "pedagogical approaches that foster the learning of disciplinary knowledge simultaneously with personal and interpersonal skills, and product, process, system, and service building skills" (Malmqvist et al., 2020). Resilience skills can be introduced and reinforced only through the use of pedagogical approaches that expose students to VUCA, in an integrated approach. The CDIO learning assessment standard could be extended with Bloom-based proficiency levels, starting from level 1 with exposure to VUCA situations, to higher levels where students are expected to lead and innovate in VUCA situations.

CONCLUSION

The aim of the paper was to compare and discuss T&L activities addressing VUCA and resilience, occurring at different engineering curriculum levels. The four presented courses are good examples of progressive contextualization of VUCA contexts for students, from freshmen to postgrads. Furthermore, as discussed in the paper and as reflected in the progression of the four courses, introducing resilience is a logical continuation after addressing VUCA-like scenarios, at least in engineering education. Based on the need for aligning curriculum integration with new learning outcomes, engineering curricula can echo in their intentions, within a framework of development such as the CDIO, the inclusion of VUCA and resilience. The emphasis on rapid changes that are a part of VUCA is highlighted in the most recent upgrade of the CDIO syllabus, although VUCA and resilience could be stated more directly.

As already argued, it is critical that engineering students develop resilience skills in order to prepare them for a VUCA shaped workplace. Previous research has emphasized the importance of developing the necessary skills to enter the workplace, contributing to high-level goals to ensure that engineering graduates are able to fit in well to their work (Gerwel Proches et al., 2018). VUCA is the 'new normal', and while there may be little that can be done about the external factors, what academics can concentrate on is to strengthen the internal aspects (Garti & Dolan, 2021). So far, however, there appears to be few approaches addressing such training. Based on the experience of comparing four different courses, the paper delineates how engineering programs can better prepare their graduates to design more resilient socio-technical systems, including effective learning methods and learning outcomes.

While we cannot generalize beyond our individual contexts, the paper does offer valuable insights and indicates areas of study which could be explored in further research. First, a continuum of the four cases with a same cohort is to experience for validating arguments and meet research questions. In the future, new evaluation techniques will be required for programs, like the ones presented in the paper. For such, a direction could draw on more formal qualitative and quantitative analysis to compare the T&L approaches with learning outcomes proficiencies.

The resilience of the higher educational system itself could be explored, by examining curriculum properties to face VUCA circumstances. Future research could also explore how to develop the VUCA and leadership skills of program managers and faculty to ensure resilience of their programs. As change agents, an examination of the approaches to reinforce program managers' and faculty's capability to handle the unknown, and to ensure that the curricula and educational systems they manage become sustained by resilient characteristics, is indeed necessary. As highlighted in the CDIO Standard on Enhancement of Faculty Competence, "the collective faculty needs to enhance its engineering knowledge and skills so that they can provide relevant examples to students and also serve as individual role models of contemporary engineers" (Malmqvist et al., 2020). This will promote the development of faculty capable of facing VUCA situations, thus ensuring better resilience of the higher educational system itself.

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CASE STUDY ON INTEGRATED CURRICULUM USING SPIRAL CURRICULUM MODEL FOR CHEMICAL ENGINEERING

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ABSTRACT

This paper shares the experience of the Diploma in Chemical Engineering (DCHE) offered by Singapore Polytechnic (SP) in using the CDIO Framework to guide the design and implementation of the integrated curriculum for chemical engineering students through a spiral curriculum model. An anchor chemical plant, namely Amine Treating Unit (ATU) is used to introduce simple concepts to the students first, which are then revisited and re-construed in a more in-depth and elaborated manner throughout the three-year course. The CDIO learning outcomes are intertwine into the context of learning to support the levelling up of knowledge and skills from one semester to another, from one module to another, while integrating critical thinking skills with disciplinary knowledge to provide a more holistic approach to engineering education for our students. The paper first introduces spiral curriculum for chemical engineering and explains how the modules are sequenced within the three-year course based on the complexity of concepts, context of learning as well as opportunities for application and integration of knowledge. Then, it describes the use of ATU chemical process plant as a case study to deliver the spiral curriculum where knowledge and skill competencies are levelled up via a series of modules offered within the 3-year diploma course. Learning opportunities are created for students to revisit knowledge and content at different stages of the curriculum, activate prior knowledge and integrate knowledge and skills. Surveys were carried out to evaluate the effectiveness of student learning. It was found that when the same case study is used, students are familiar with the case and are more receptive to building new knowledge, hence making connections between prior knowledge and new knowledge. Faculty teaching staff make deliberate efforts to point out how the concepts are related and connected, how the concepts are levelled up from one level to the next so that students make personal meaning of knowledge and see how it is used in real world applications and problem-solving. In the last section of the paper, it outlines the broad areas where the delivery of the spiral curriculum can be further improved and enhanced to better support student learning.

KEYWORDS

Chemical Engineering, Spiral Curriculum, Anchor Case Study, CDIO Standard: 3

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". A "course" in the Diploma in Chemical Engineering consists of many subjects that are termed "modules"; which in the universities contexts are often called “courses”. A teaching academic is known as a "lecturer", which is often referred to a as "faculty" in the universities.

INTRODUCTION

The Diploma in Chemical Engineering (DCHE) course offered by Singapore Polytechnic (SP) had adopted CDIO as the basis for revamping its curriculum since 2007 and its “CDIO-enabled” curriculum was introduced for the first time in April 2008 for students in the Academic Year (AY) 2008/2009 cohort (Cheah, 2009). There was a need to shift the curriculum model, which was largely content driven and taught in silos with little connectivity between modules, to one focusing on key concepts fundamental to understanding and in a more integrated format [Standard 3 – Integrated Curriculum]. In addition to integration of discipline-specific knowledge in the curriculum, various generic skills such as teamwork, communication and critical thinking were integrated into carefully designed learning activities in laboratory sessions or assignments to core chemical engineering modules.

Since then, a national initiative named Singapore Skills Framework took off which led to further review of the course to re-design and deliver appropriate learning content to meet both existing and emerging skills required for the changing industry needs and work roles. The redesign of the chemical engineering curriculum and its CDIO experiences after years of implementation were documented in various earlier papers, e.g. Cheah, Phua & Ng (2013) and Cheah & Yang (2018).

As part of a continual improvement over past efforts, the most recent revamp of the DCHE course took place in 2017 which led to the adoption of the spiral curriculum model for its course structure for students in the AY2018/2019, in response to providing a more systematic structure to build up student competencies using the CDIO approach while ensuring the curriculum retains its integrated form.

The process undertaken by the Course Management Team to carry out the transition had been described by Cheah & Yang (2018). The DCHE curriculum model shown in Figure 1 illustrates the progressive development of key competencies over the diploma’s 3-year duration.

Yang, Cheah & Phua (2021) carried out the first evaluation on the spiral curriculum in DCHE and found that spiral curriculum model benefitted student learning where key concepts and principles are revisited over time to further clarify and extend the knowledge base in terms of adding new related knowledge, enhancing integration and further refining until students make sense of the knowledge and apply them purposefully and meaningfully.

SPIRAL CURRICULUM MODEL

In a spiral curriculum, the key concepts and principles are revisited throughout the instructional process. New related knowledge are added over time to extend the knowledge base, enhance integration of concepts and principles across related topics and further refine until the student’s mental schemata comprises of most accurate and appropriate mental representation of the concepts and principles.

Through the spiral curriculum model, the DCHE course aims to enable students to build knowledge and skills progressively and in an integrative manner from one semester to another so that students can apply knowledge and skills purposefully and demonstrate competence in both technical and non-technical skills during their internship programme.

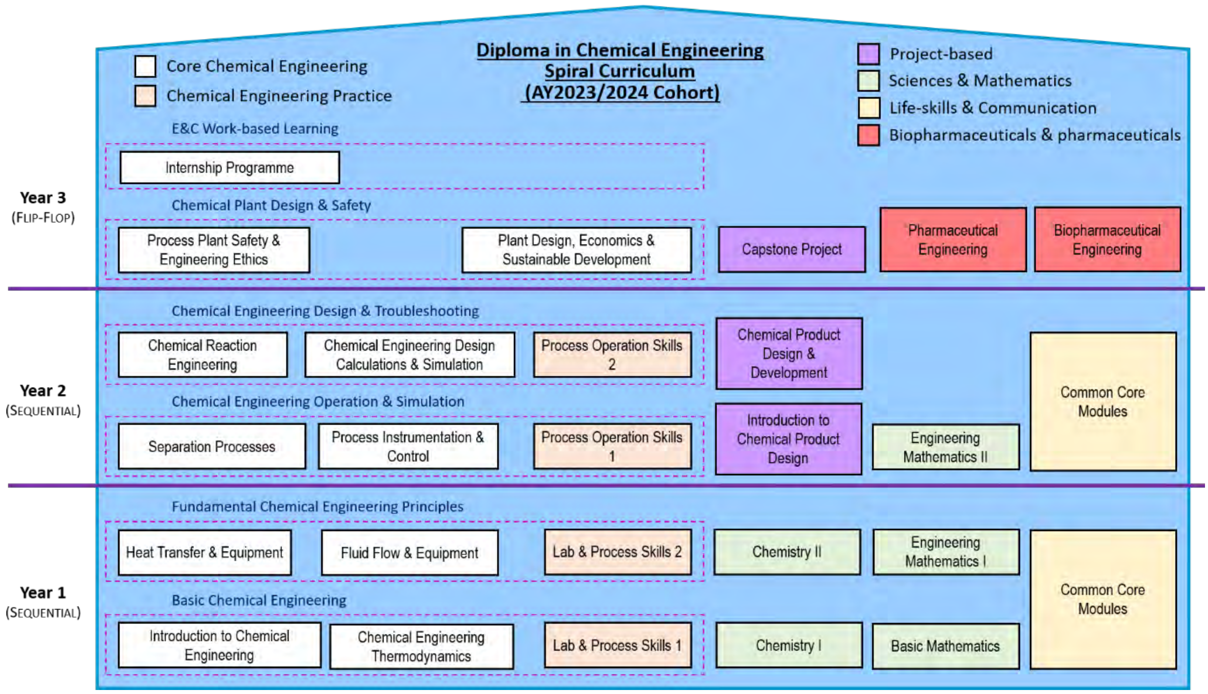

Figure 1. The DCHE Spiral Curriculum Model

Spiral curriculum is a concept widely attributed to Bruner (1960), who refers it as a curriculum design in which key concepts are presented repeatedly throughout the curriculum, but with deepening layers of complexity, or in different applications. Bruner (1960) believes that "any subject can be taught in some honest form and a curriculum would be structured around the great issues, principles and values that a society deems worthy of the continual concern of its members". Bruner (1960) also asserted that "we begin with the hypothesis that any subject can be taught effectively in some intellectually honest form to any child at any age of development."

It is through the systematic teaching of key concepts, and varying degrees of complexity and elaboration, over the duration of the curriculum that were most fundamental to the approach. Indeed, within the field of cognitive neuroscience, there is much validation to Bruner's (1960) conceptions. The importance of teaching key concepts that are fundamental to understanding, and the need for spaced and deliberate practice over time to ensure that knowledge and skills are encoded and cemented in long-term memory is well validated by Brown, Roediger, & McDaniel (2014).

Since then, a number of implementations at academic institutions in different countries have adopted the spiral curriculum model, such as those in medicine (Brauer & Ferguson, 2015; Harden & Stamper, 1999), mathematics curriculum for primary education in Singapore (Ministry of Education, 2007), online learning courses (Masters & Gibbs, 2007), undergraduate chemical engineering degree courses (Gomes, Barton, Petrie, Romagnoli, Holt, Abbas, Cohen, Harris, Haynes, Langrish, Orellana, See, Valix, & White, 2006; Gupta, Joseph, Alcantar, Toomey, & Sunol, 2008), and chemical engineering master degree program (Neumann, Neumann, & Lewis, 2017).

Gomes et. al. (2006) and Gupta et. al. (2008) believe that spiral curriculum is a superior learning approach because it allows students to "master each increment of subject in hierarchical sequence before going on to the next" (Gupta et. al., 2008). In fact, Gomes et. al. (2006)'s study reveals that there is significant increase in student engagement within the broader learning process. Masters & Gibbs (2007) finds the spiral curriculum to be very effective for online learning if the practice is used consistently.

INTEGRATED CURRICULUM USING SPIRAL CURRICULUM MODEL WITH AMINE TREATING UNIT (ATU) AS ANCHOR CASE STUDY

Chemical Engineering is a broad discipline where the knowledge, concepts and skills taught can be applied to different processes, such as chemical, pharmaceutical and biological. Amine, being very effective in removing carbon dioxide (CO_2) and hydrogen sulfide (H_2S), is commonly use in refinery and petrochemical plants to remove acid gases. Thus, it is chosen as an anchor case study for the DCHE course. The Amine Treating Unit (ATU) is selected as an anchor case study to support the integrated curriculum using the spiral curriculum model through the three years of studies in DCHE. An anchor case study serves to provide students with a single process to develop deep familiarity with, and use it to build increasingly more complex concepts and extend the knowledge learnt. Students will not need to spend time understanding new processes before being able to apply concepts taught. The presence of the familiar case study will aid students in learning new concepts (Reder, Liu, Keinath, & Popov, 2016). When incorporating this ATU case study into the various modules in the course, existing content and learning outcome in the curriculum remain unchanged. The ATU case study merely replaces the scenarios used to teach the concepts that were already there.

There are two main steps in ATU as shown in Figure 2:

- 1st Stage: Amine Absorber whereby acid gases are bought in contact with amine and the gases are absorbed in the liquid amine.
- 2nd Stage: Amine Stripper whereby the acid gases are stripped away from the liquid (amine). This is to regenerate lean amine solution and recirculate it to the amine absorber.

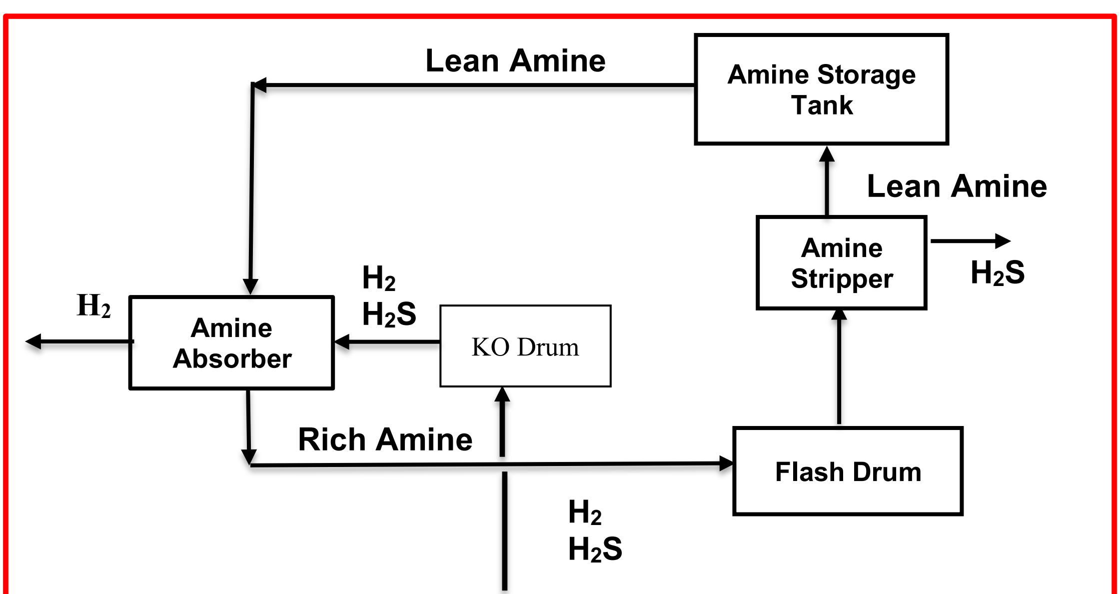

Figure 2: Amine Absorber and Amine Stripper in ATU

Amine Treating Unit (ATU) as Anchor Case Study for Year 1

In this integrated curriculum effort, students in their Year 1 studies are provided appropriate scaffold to guide their learning when using the ATU. As the context becomes more complex in Year 2, the learning scaffold is gradually removed so that students learn to become more self-directed and develop resilience to solve more complex problems using the ATU. Finally in Year 3, students are expected to apply concepts and principles without explicit instructions where it is hoped that the spiral curriculum model in the DCHE course has enabled them to develop some form of mastery, think in-depth and have the confidence to solve real-world problems.

ATU is used as a group assignment in the first core module for Year 1 students in a Semester 1 module, named *Introduction to Chemical Engineering*. In this module, students were first introduced to various unit operations (basic step in process) commonly used in the chemical industry. After which, the topic of Process Flow Diagram (PFD) is taught. A PFD is a diagram commonly used in chemical and process engineering to indicate the general flow of plant processes and equipment. In the assignment, the process description of ATU is provided. Students are required to construct a PFD for amine treating system using Microsoft Visio software by applying standard requirement of preparing PFD. Four unit operations, namely Amine Absorber, Rich Amine Flash Drum, Amine Stripper and Lean Amine Storage Tank are to be included together with process accessories such as control valves, pumps and heat exchangers where appropriate. A sample of the deliverable PFD is shown in Figure 3.

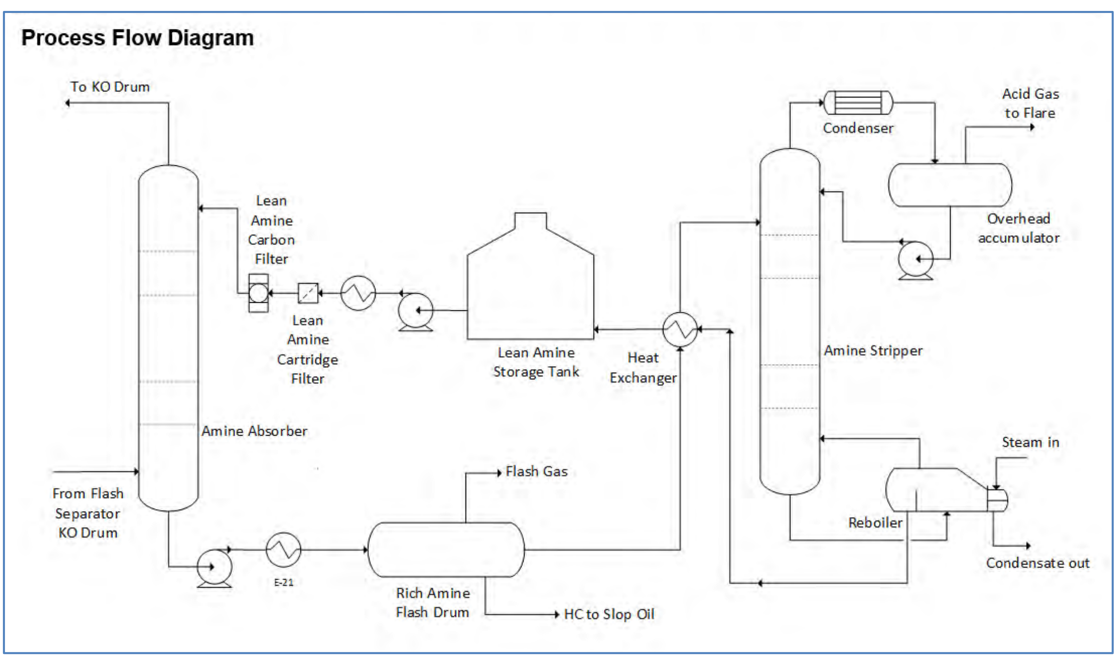

Figure 3: ATU PFD – A sample of deliverable of the group assignment for *Introduction to Chemical Engineering* module

In the second core module for Year 1 students, named *Chemical Engineering Thermodynamics*, the same ATU PFD is used in a group assignment as an extension to the assignment completed earlier. In this module, students were introduced to the fundamentals of 1st Law of Thermodynamics and were then taught how to apply it to various equipment such as pumps and heat exchangers commonly used in a chemical plant. In the group assignment, students are required to apply 1st Law of Thermodynamics and perform engineering calculations on both the heat exchanger, E-101 and pump, P-201 as shown in Figure 4. Students are subsequently required to describe how changes in stream composition entering heat exchanger, E-101, have a direct impact to its outlet temperature. In order to describe the impact, they are required to have an understanding about feed composition and specific heat capacity. The knowledge of feed composition was covered in an earlier module (*Introduction to Chemical Engineering*). The students will have learnt about specific heat capacity in *Chemical Engineering Thermodynamics* module. So, in this assignment, the students demonstrate their ability to draw the connection between feed composition and specific heat capacity of the process fluid and how the relationship between these two knowledge can affect the heat exchanger operation. With this, students have the opportunity to revisit a concept and then add new related knowledge over time to extend their knowledge base and enhance integration.

In addition, the students were further challenged to predict how the changes in stream composition entering the heat exchanger eventually affect the heat exchanger duty and subsequently the downstream process after the heat exchanger. Students will derive the Bernoulli's equation from the 1st Law of Thermodynamics based on pump P-201 in Figure 4. This derivation is commonly applied in calculations involving pumps. This enables students to better understand the basis of the Bernoulli's equation which eases them into application in other context that are covered in a follow on module named *Fluid Flow and Equipment*. In the assignment, student will make use of the Bernoulli's equation to study the effect of liquid level in the Lean Amine Storage Tank on the pump power requirement for pump P-201.

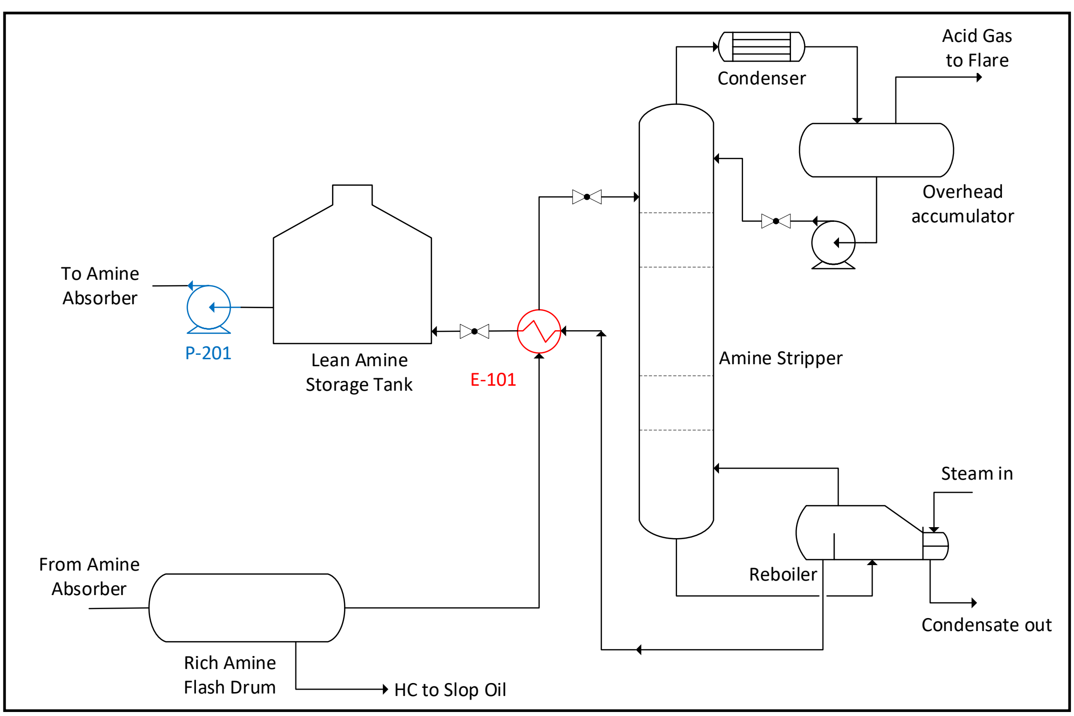

Figure 4: Selected equipment from ATU used in *Chemical Engineering Thermodynamics* assignment

In the third core module for Year 1 students, named *Heat Transfer & Equipment*, ATU is used for students to identify the type of heat exchangers from the Process Flow Diagram of ATU.

Based on the Process Flow Diagram, students are first required to identify the service type of the heat exchangers, i.e. either cooling or heating. Then based on the service type identified, the students are to make recommendations on the appropriate type of medium to match the service type. These tasks require students to leverage on their prior knowledge about unit operation.

Through a group assignment, students analyse the process parameters and derive the heat exchanger duty required in order to design a heat exchanger in the ATU to meet the process requirement. In addition, the concept of heat integration is introduced to create awareness in the effort of sustainability in chemical industry. Students have to compare the heat source required with and without the heat integration and evaluate the advantage of heat integration in chemical plant. This group assignment enables the students to work on more complex problems that mimic the chemical industry.

In the fourth core module for Year 1 students, named *Fluid Flow & Equipment*, a higher level of application of 1st Law of Thermodynamics is introduced. Students have to derive the Bernoulli's Equation to compute the pump power requirement for pump sizing, taking into consideration of various friction losses along the pipe line. Again, this demonstrates the increasing complexity and elaboration of the concepts and principles taught in the DCHE curriculum. This module is the concluding module in the Year 1 curriculum and wraps up the fundamental knowledge and concepts needed for Year 1 students to move on to their studies in Year 2.

In general, Year 1 modules provide fundamental concepts to prepare students to tackle and solve more complex engineering problems in later years in a course. In our work, we realised that there are many opportunities to inject levelling-up learning tasks for students even at Year 1 level. With the four Year 1 core modules providing the levelling-up experience for students, Year 2 core modules also follow suit and continue to use the ATU case study as the anchor plant to deliver the spiral curriculum.

Amine Treating Unit (ATU) as Anchor Case Study for Year 2

The ATU is first used to activate prior knowledge in the first core module for Year 2 students, named *Separation Processes & Simulation.* Students are shown Figure 5 and required to recall knowledge, such as unit operations, heat transfer and fluid flow concepts related to the ATU, and principles and types of heat exchangers, pumps, and valves, learnt in various modules in the previous year.

The ATU is next used to show the linkage of concepts that will be taught in the two core modules in Year 2, *Separation Processes & Simulation*, and *Process Instrumentation & Control*. In *Separation Processes & Simulation* module, students learn about the principles of two separation processes, namely flash drum, gas absorption / stripping that are present in the ATU. Students also had to compare and contrast gas absorption and stripping processes so that they do not merely know these processes but also understand the differences and similarities between these separation processes providing an opportunity for students to think in-depth. Once the students understand the separation processes concepts, the ATU can be used to extend learning through the application of process monitoring and appropriate control strategies for those processes in the second core module in Year 2 named *Process Instrumentation and Control* where students learn about process instrumentation, and basic and advanced process control concepts.

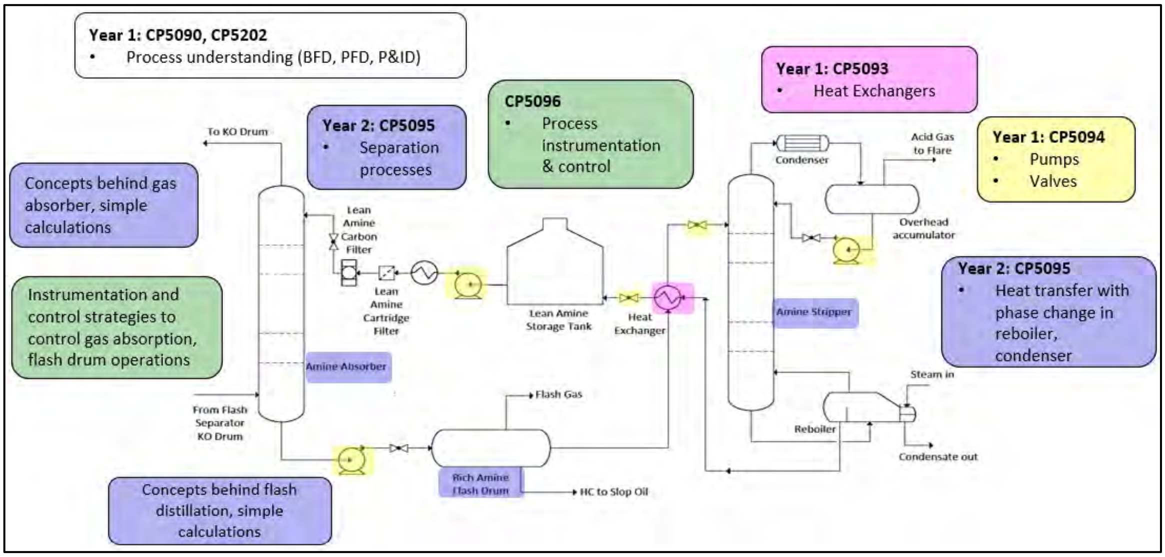

Figure 5: Process flow diagram of ATU used to activate prior knowledge and link concepts taught in *Separation Processes & Simulation* module

Amine Treating Unit (ATU) As Anchor Case Study For Year 3

The final module in the DCHE curriculum that uses the ATU case study is in *Process Plant Safety and Engineering Ethics* module in Year 3. This module leverages on students prior knowledge on unit operations, heat transfer, fluid flow, separation processes, instrumentation and control to conduct a hazards operability study (HAZOP). A HAZOP study is a structured and systematic examination of a complex plan to identify and evaluate problems that present risks to personnel and/or equipment during operation. When the students conduct the HAZOP study using the ATU case study, it presents them an increasingly complex scenario where there are various dimensions to consider as opposed to the scenarios presented to them in Year 1 core modules. This certainly mirror a real engineering problem with many aspects for students to cogitate, understand and apply their competence that they have mastered through the 3 years of studies in DCHE.

SURVEY RESULTS ON SPIRAL CURRICULUM

With the implementation of the spiral curriculum module, the Course Management Team is interested to understand its impact on student learning. Hence, a quantitative survey was conducted at the end of each semester. Specifically, students were asked to indicate on a 5-point Likert scale the extent to which they agree or disagree with the following statements with 1 being Strongly Disagree and 5 being Strongly Agree.

Question 1: I was able to see connections between what was taught in different modules.
Question 2: I can understand the basic engineering concepts better.
Question 3: The spiral curriculum challenges me to think in depth (e.g. analyse, compare and contrast, evaluate)

Two cohorts of students were surveyed. The first cohort participated in the survey in AY2018/2019, when they were in Year 1, and again in AY2019/2020 when they progressed to Year 2. The second cohort was surveyed in AY2019/2020 when they were in Year 1, and again in AY2020/2021 when they moved to Year 2.

Figure 6 shows the response obtained from Year 1. Based on the responses obtained, 63% (AY2018/2019) and 80% (AY2019/2020) of the students agreed that they are able to “see the connections” among the modules where spiral curriculum enhances students’ ability to integrate knowledge learnt and strengthen their ability to solve problem of higher level of complexity. In another words, the integrated curriculum had enabled students to link the key concepts from one core module to other core modules.

60% (AY2018/2019) and 79% (AY2019/2020) of the students agreed that the spiral curriculum enables them to better understand the basic engineering concepts and 64% (AY2018/2019) and 73% (AY2019/2020) of the students agreed that the spiral curriculum challenges them to use higher order thinking skills such as compare, contrast and solve engineering problems. This enabled students to build on key concepts at the beginning of the semester and complex concepts are then developed more elaborately throughout the semester in different context whereby students develop critical thinking skills within the chemical engineering context.

Through a focus group discussion with students, they shared that the basic engineering concepts taught in *Introduction to Chemical Engineering* module laid the foundation needed for them to connect with the concepts taught on *Chemical Engineering Thermodynamics* module. In the DCHE course, the assignments challenge students to work in groups, analyse the problems and devise appropriate solutions by applying chemical engineering concepts taught in the modules.

Overall, there is a significant improvement in the students’ feedback from AY2018/2019 to AY2019/2020. This is primarily due to the continuous effort by the module team to improve the delivery of the flow of module contents.

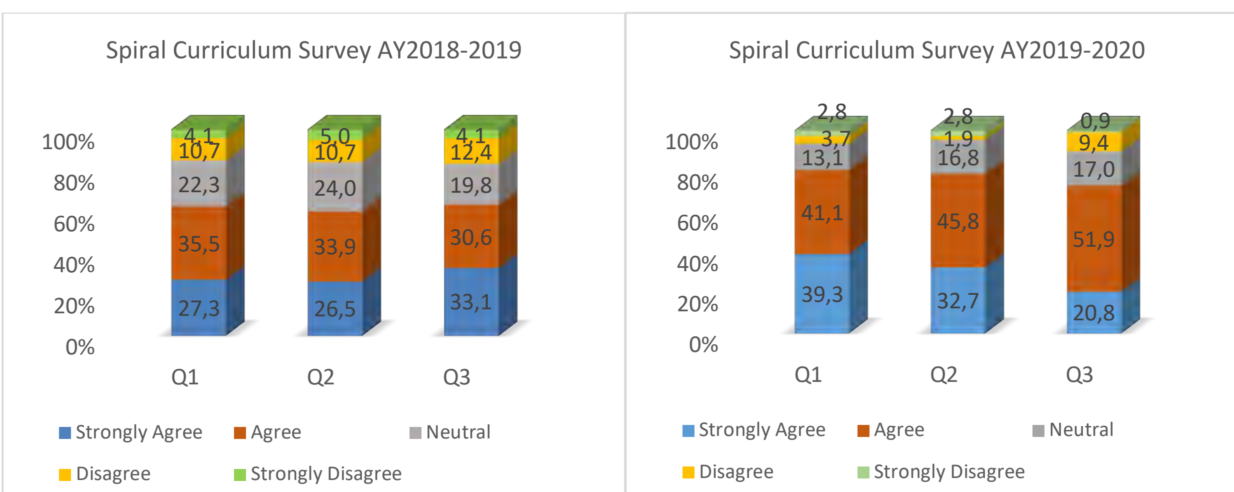

Figure 6. Students’ Responses on Spiral Curriculum in Academic Year (AY) 2018/2019 & 2019/2020 for Year 1 students

In summary, the quantitative survey result obtained was encouraging with majority of the students either “Agree” or “Strongly Agree”, indicating strong alignment to the intended outcome.

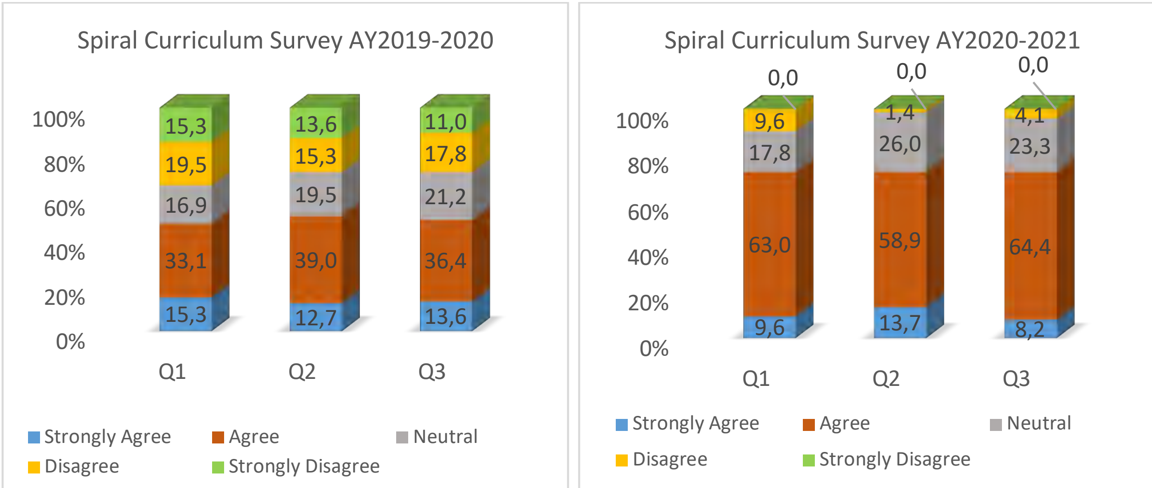

Figure 7. Students' Responses on Spiral Curriculum in Academic Year (AY) 2019/2020 & 2020/2021 for Year 2 students

Figure 7 shows the students' responses on spiral curriculum when they progressed to Year 2 in AY2019/2020, and AY2020/2021. When the students moved onto Year 2, 48% (AY2019/2020) and 73% (AY2020/2021) of students agreed that they are able to "see connections" among the two modules (*Separation Processes & Simulation*, and *Process Instrumentation & Control*) taught in that year. 52% (AY2019/2020) and 73% (AY2020/2021) of the students agreed that the spiral curriculum enables them to better understand basic engineering concepts. 50% (AY2019/2020) and 73% (AY2020/2021) of students agreed that the spiral curriculum challenges them to use higher order thinking skills. Similar to the survey outcome for Year 1 students, there is an improvement in the students' feedback from AY2019/2020 to AY2020/2021 for Year 2 students for the two different cohorts.

When the survey outcomes were compared within the same cohort of students, the percentages of students who agreed that they were able to "see connections" among modules (63% in Year 1 and 48% in Year 2), that the spiral curriculum enables them to better understand basic engineering concepts (60% in Year 1 and 52% in Year 2), and that the spiral curriculum challenges them to use higher order thinking skills (64% in Year 1 and 50% in Year 2) dropped for the first cohort of students when they progressed from Year 1 to Year 2. However, for the second cohort of students, comparable percentages of students agreed that they were able to "see connections" among modules (80% in Year 1 and 73% in Year 2), that the spiral curriculum enables them to better understand basic engineering concepts (79% in Year 1 and 73% in Year 2), and that the spiral curriculum challenges them to use higher order thinking skills (73% in Year 1 and 73% in Year 2) even when they moved from Year 1 to Year 2. This is primarily due to the Year 2 lecturers putting in deliberate efforts to strengthen linkages between and within the modules and improving the flow of module delivery, upon reflecting on the results from the first cohort of students.

PLANS FOR MOVING FORWARD

This section discusses plans for moving forward such as opportunities to widen the use of ATU as the anchor case study, integration of other CDIO skills and incorporation of sustainability into the DCHE course.

Moving ahead, the connections between what was taught in different modules can definitely be strengthen in Year 2 using ATU. For instance, a learning task could be introduced in *Separation Processes & Simulation* module for students to explore the impact of changing solvent rate specially for the amine absorber. In *Process Instrumentation & Control* module, there are ample possibilities to incorporate applications in terms of control strategies to the separation processes in ATU such as the flash drum, and amine absorber / stripper. Furthermore, in Year 2, it can be assumed that students already have the knowledge of the principles, function and operation of every unit operation at this stage of study. Lesser learning scaffold can be provided to students so that they can inculcate more independent learning and allow them to be more self-directed. There are more opportunities for them to make inquiry and seek clarification so that they become more independent learners. So, when the students are given a separation process in the ATU to apply process control principles, they will have to analyse the given information themselves, can be tasked to sketch appropriate process control scheme to achieve desired control objective and suggest suitable instrument set points to attain specific safety objective.

Through the survey outcome, the delivery of technical content using the ATU case study and spiral curriculum model indeed enhanced student learning. There remain other opportunities for the Course Management Team to integrate other skills into the curriculum such as digital skills and development of resilience through learning from failure (Shepherd, 2004). The Course Management Team can also evaluate teamwork skills as part of the integration of skills and attitude in the spiral curriculum through the use of appropriate validated instrument like Comprehensive Assessment of Team Member Effectiveness (CATME) that assesses effective teamwork (Ohland, Loughry, Woehr, Bullard, Felder, Finelli, & Schmucker, 2012).

In 2022, Singapore Green Plan 2030 was launched as a national movement to advance Singapore's national agenda on sustainable development. This forms a mandate for educational institutions to include sustainability into its curriculum so that graduates who join the workforce in future will be able to propagate green practices into the industry and strive to build a sustainable future nationally and internationally. There is an opportunity to infuse sustainability using the ATU through alternative low energy technologies that could be used in place of ATU to remove acid gases, and let students perform a comparison between the two technologies, or to conduct literature research on alternative green solvents that can be used instead of amine.

CONCLUSION

In conclusion, the use of ATU case study and spiral curriculum model have benefitted student learning where students revisit chemical engineering concepts and principles over several modules and across semesters. The complexity of the context increases with every revisit of the ATU case study. This provides opportunities for students to deliberately practice their understanding of the concept while extending the knowledge base in terms of adding new related knowledge, enhancing integration and further refining until students make sense of the knowledge and apply them purposefully and meaningfully.

Our study has shown that the use of a simple process, such as the ATU case study, when infused purposefully into selected modules in the DCHE course using the spiral curriculum model, enabled students with little chemical engineering knowledge to build familiarity with this process and progressively learn and apply core chemical engineering concepts and principles at various stages of the course.

The Course Management Team also identified opportune areas to further enhance the integration of other skills sets in the DCHE course, for example CDIO skills (teamwork and communication) as well as future skills (digital skills and versatility). Making connections with concepts taught in different modules can be strengthen to enhance student learning and ways to infuse sustainability concepts meaningfully into the course are areas for improvements.

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A CDIO APPROACH TO TEACH SUSTAINABILITY IN ARCHITECTURE

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ABSTRACT

The CDIO initiative, an educational framework that comprises 12 standards for evaluating and reforming engineering programs. The framework has become a guiding principle for program leaders to reform and evaluate curriculums, create benchmarks, and align learning goals with worldwide application, making it a framework for continuous improvement. The School of Architecture and the Built Environment (ABE) at Singapore Polytechnic adopted the CDIO framework to guide non-engineering diploma programs towards continuous improvement. A professional development course was designed by the ABE Teaching & Learning (T&L) unit to coach program leaders on evaluating their programs. Their initial task after completing part 1 coaching was to map their diploma program to CDIO standards.

This paper focuses on how one of the non-engineering programs, a three-year Diploma in Architecture from the Singapore Polytechnic, maps itself to CDIO (Conceive, Design Implement, Operate) standards, specifically CDIO 3.0, with a specific emphasis on sustainability. This paper first discusses how sustainability knowledge has been incorporated in the program (vertical integration), levelling up progressively over the three years of the program. It then describes the mapping of CDIO standards in the program via three threads: 1) the process of architectural practice; 2) Skills framework for the Architecture sector; 3) Green Mark 2021. The program addresses 10 out of the 17 United Nations Sustainable Development Goals (SDGs) and implements them through a horizontal integrated year two curriculum. The selected course, Design Studio I (Architecture) (DS1(A)) is centered on an integrated design project that provides students with the opportunities to apply and contextualize sustainability knowledge, skills, and attitudes with technological advances. This paper also presents the findings from students' feedback and learning reflections of DS1(A) as well as the teaching team's perspectives. It then concludes with considerations of incorporating sustainability and the challenges of teaching sustainability in DS1(A).

KEYWORDS

Sustainability development, design-implement, architecture, non-engineering, CDIO standard 1, 2, 3 and 5 and CDIO optional standard 1.

BACKGROUND

CDIO has been the anchoring curriculum framework for engineering courses in the Singapore Polytechnic since 2004. In 2021, the School of Architecture and Built Environment (ABE) Teaching and Learning Unit (TLU) launched an enhanced professional development program (CDIO standard 10) for program leads to strengthen their current program curriculum as well as teaching and learning approach. It also aims to widen its reach to non-engineering programs. The program leads of six diplomas in ABE were trained to map their curriculum onto CDIO 12 standards, focusing on making sustainability more visible to teaching staff and students and strengthening it using the CDIO approach. Out of these six programs, one is engineering and five are non-engineering. This paper then focuses on one of the non-engineering programs, a three-year Diploma in Architecture (DARCH), maps itself to CDIO standards, specifically CDIO 3.0, where sustainability (CDIO optional standard 1.0) is one of the focuses.

LITERATURE REVIEW

As the world's climate continues to be impacted by the repercussions from global warming, teaching sustainability has become a priority education at all levels. We believe that a change in people's attitudes and behaviours is essential for sustainable development. To teach sustainability is therefore to adopt teaching methods that will change students' attitudes and behaviours towards sustainability. Some of the factors that affect student attitudes and behaviors towards the environment and sustainability include knowledge and level of awareness (Sahin & Erkal, 2017), as well as economic issues (Rosentrater & Burke, 2017). There are two approaches to stimulate increased levels of care for the environment and pro-environmental attitudes and behaviors (Pizmony-Levy & Michel, 2018). The two approaches are: one, through extra-curricular activities where students participate in sustainability events and initiatives that raise awareness of environmental issues and promote sustainability. The second approach, which is also the focus of this paper, is to integrate sustainability components into curriculum through a design-implement project. This can be done through the vehicle of an integrated design project where the students design a multi-storey residential development, stimulating professional practice by conceiving, designing, and implementing their project. This provides a practical and experiential experience in nature, related to real life conditions while gaining knowledge, involving students in critical thinking and reflection on action.

Technology, especially related software plays a key role in supporting the teaching of sustainability (Marouli, et al., 2016a). Example such as simulation software introduced to students for used in their project to analyse urban forms in relation to shadow, wind and solar insolation.

INTRODUCTION

Originally named as Diploma in Architectural Technology (DAT), the DARCH program began in Singapore Polytechnic as a drafting course in 1958, providing vocational training for students who will move on to fill the role of draftsman upon graduation. In the year 2003, the program adjusted its curriculum to expand its graduate profile from a draftsman to the role of an architectural assistant. With this adjustment, the program was then renamed as Diploma in Architecture (DARCH).

The key change in this adjustment is the introduction of design into the curriculum, allowing students the opportunity to apply the technical disciplinary knowledge acquired from the supporting courses/modules into a design project. This incorporation of design created a more varied, creative and competitive environment where students can thrive in being more innovative and solution-minded. Figure 1 shows a breakdown of the courses taken by students in their third year and how these individual courses contribute to a central design project known as the 'Integrated Project'.

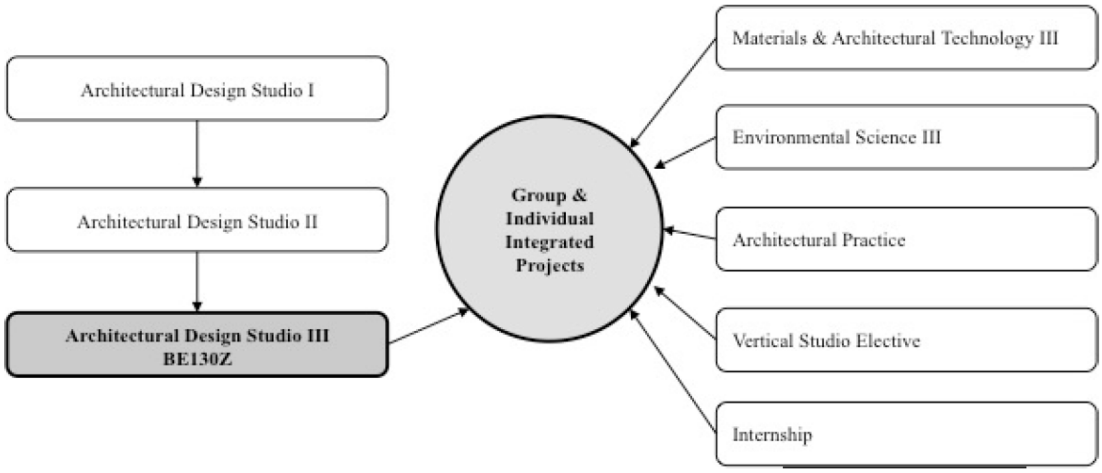


Figure 1 DARCH Integrated Project Pedagogical Framework

This new pedagogical framework mirrors the real-life phases of architectural production, allowing the students to easily assimilate to the actual process when they enter the workforce after graduation. In Singapore, these phases are articulated sequentially as ‘Concept Design’, ‘Schematic Design’, ‘Design Development’, ‘Construction’ and ‘Completion’. As the names suggest, each phase is a development from the earlier phase, the project begins with abstract concepts, takes on schematic form, moving on then into details, before culminating in the actual construction of the building. The integrated project approach emulates this process through a series of curated learning activities that progress through the same stages and enabled by the vehicle of an individual design project.

What has just been described resembles the CDIO framework. Since the transition to DARCH, the faculties recognise that architectural students in training should be able to Conceive-Design-Implement-Operate complex value-added architectural schemes in modern team-based environments. They should be able to participate in the practice of architecture, contribute to the development of architectural design and work at professional standards. The architectural profession is not unlike the engineering profession in this aspect.

The likeness of the current structure in the DARCH pedagogy to CDIO makes the idea of articulating the curriculum as a CDIO curriculum potentially feasible and beneficial to the program as it allows the program to be evaluated and developed through an established system that is already in place.

THE CDIO MAPPING CHART

The adoption of a full CDIO framework for the entire DARCH program can be an arduous and lengthy exercise, especially for a non-engineering program with no prior experience. To simplify this initial transition, a decision was made to narrow the scope by focusing only on the aspect of sustainability. Besides easing the process, the focus on sustainability is also appropriate and strategic at this point in view of the current global trends as well as the introduction of the new CDIO 3.0 Syllabus. The following sections will describe how CDIO, as an education framework helps the program systematically breakdown the industry needs pertaining to sustainability and infuse the necessary skillsets into the curriculum.

To facilitate the mapping across to the CDIO framework, a chart to visualise and organise curriculum activities into the ‘Conceive’, ‘Design’, ‘Implement’ and ‘Operate’ stages of design was created. The intent for this chart is to allow the existing curriculum activities to be sorted into the respective columns presenting a basis for an initial assessment of the program with regards to CDIO in the short term. Eventually, this 'live' chart will continue to aid the program lead and faculties in their design of the curriculum.

Running horizontally across the chart are the CDIO stages, starting with 'Conceive' on the left and ending with 'Operate' on the right, thereby forming the 'CDIO Stages' axis. Then running downwards, perpendicular to the CDIO axis, are the 12 standards of CDIO, arranged in its numerical order. This forms the 'CDIO Standards' axis. Together, these 2 axes allow curriculum activities or outcomes to be understood in relation to 2 particularly important aspects of the CDIO framework - the stage of the CDIO stages that they fall under and the CDIO standards they fulfil. As the entire chart is too large in scale, only a portion of it is reproduced in Appendix A.

USING CDIO STANDARDS TO DISSECT THE PROGRAM

This next section will describe the process of adoption where the CDIO standards were used to dissect the program requirements to gain a better understanding of where the curriculum stands with regards to the framework. This exercise also created focused investigations around particular aspects of the program, allowing gaps if any to be revealed. Since this mapping exercise focused only on mapping sustainable learning experiences into the program, the CDIO standards that were referenced were taken from the CDIO Optional Standards 3.0, Optional Standard 1 – Sustainable Development. Reference was also made to the *Rubric for self-assessment* (Crawley, 2022) to position the program based on its current offerings. And to ensure a more purposeful mapping exercise a target of level 3 on the rubric scale was set as the preliminary goal. This would therefore require the program to demonstrate that "explicit program goals and intended learning outcomes related to environmental, social, and economic sustainability and at least three substantial sustainable development learning experiences of increasing complexity including an introduction early in the program." (Crawley, 2022).

The dissection of the program using the lens of the CDIO standards was implemented according to the numerical order of the standards. However, this paper will only cover in detail Standard 1 and 2. The next few paragraphs will attempt to explain how the mapping helped the program emphasize environmental, social and economic sustainability as the context of the program. It will also explain how after the context is established; the context in turn frames the learning outcomes of the program.

While *Conceiving* – *Designing* – *Implementing* – *Operating* forms the primary context of the CDIO education model, there seems to be also a need to articulate secondary context(s) that would help clarify the needs of the industry. And in our case here, it is important to identify from the start a point of reference that can narrow down the relevant skillsets needed by the graduates to conceive, design, and implement sustainable architectural solutions acceptable by the industry.

The most common point of reference today appears to be the United Nations Sustainable Development Goals (UN SDGs). However, these set of goals are quite broad in definition, making the actual tie back to a specialised course such as architecture challenging. This led to a further industry scan, which surfaced another plausible point of reference that is more specific and relevant to the profession. This alternative point of reference that can form the secondary context is the Green Mark 2021.

Green Mark or Green Mark Certification Scheme is a rating system developed by the Building and Construction Authority (BCA) of Singapore since 2005 to evaluate a building's environmental impact and performance. In tandem with the Code for Environmental Sustainability of Buildings that came in force in 2008, these 2 building guidelines regulate and incentivise the development of sustainable building designs in Singapore.

Green Mark 2021 is the most current release of this rating system, and it consists of 6 different sections – (1) Energy Efficiency, (2) Intelligence, (3) Health & Well-Being, (4) Whole of Life Carbon, (5) Maintainability, and (6) Resilience, providing a comprehensive assessment of a building's impact to the environment. Each section comes with a detailed document listing down the various expected sustainable features or considerations required of a building design. It became obvious that if industry practitioners are obligated to meet these expectations, then students too ought to be trained with the needed skillsets. The pegging of the program to this building sustainability rating system as the secondary CDIO context will therefore ensure an alignment of the graduate profile to the industry needs.

Two interesting discoveries were also made in the attempt to draw Green Mark 2021 into the CDIO framework as its secondary context. Firstly, a closer study of the Green Mark Criteria showed that the expected considerations for sustainable features or design responses occurs at distinct phases of the architectural project life cycle, distributed across the stages of Conceive-Design-Implement-Operate. The Green Mark requirements could then be analysed and mapped accordingly into their respective stages, allowing the secondary context to be nested within the primary CDIO context. This would mean that students can hence also experience sustainable learning activities in accordance with the CDIO approach.

Secondly, the Green Mark 2021 Sections was found to be mapped to the UN SDGs by the authors of the rating system (BCA, 2021a). This added value to the choice of adopting Green Mark 2021 as the secondary context as it meant that the program would still be contributing to global sustainable goals indirectly through the rating system.

GREEN MARK AS THE BASIS OF CRAFTING LEARNING OUTCOMES

After narrowing down the point of reference that could serve as a context to emphasize environmental sustainability, we then moved on to allocate the specific detailed expectations of the rating system within the CDIO Mapping Chart. Not every criterion from the rating system was transferred to the mapping chart, only relevant ones that ought to be covered by the program was included. The selected criteria were then sorted to the most relevant CDIO stage. This was done by having the criterion descriptions written in white or black coloured tiles and distributing these tiles across the CDIO Stage axis. Each criterion would therefore find itself appropriated under the Conceive, Design, Implement or Operation column (see Appendix B).

This is a crucial step, as the visualisation of these Green Mark criteria across the CDIO spectrum allows us to read them as specific program goals that will in turn direct our efforts when we craft learning outcomes. When the learning outcomes are crafted with the intent to meet these goals, we believe that this will in turn help the program fulfil CDIO's Optional Standard 2 where "sustainability related knowledge, skills and attitudes, are explicitly addressed in program goals and learning outcomes" (Crawley, 2022). Furthermore, the placement of these goals within the CDIO Mapping Chart allows faculties to be better informed of how to organise their learning activities in line with project life cycles.

As mentioned earlier, the next step of the mapping exercise involves the crafting of learning outcomes in relation to Green Mark 2021 requirements. How this was done will be explained with the help of an example where the "Contextual Response" criteria found in the Resilience Section of Green Mark 2021 was translated into 3 separate learning outcomes parked under the 'Conceive' column and to be implemented within a 15-week Design Studio I (Architecture) course.

The 'Contextual Response' criteria requires the architectural proposal to:

demonstrate how the site topography, microclimate, access and connectivity has informed the design of the urban form and site layout. A site analysis should be conducted to identify the relationships between human and physical geography of the site and inform how the building responds to these factors. Details should include the response to the urban grain, site connectivity and access, provisions and locations of amenities, and opportunities for green corridors. A series of simulations and studies of the project should also be undertaken that look at the microclimate and the response of the urban form generated, including, shading analysis, wind analysis and solar insolation studies. (Building Construction Authority (BCA), 2021b)

This work of analysing a project site occurs prior to the design of buildings, meaning during the 'Conceive' stage. Buildings designed empathetic to site conditions often takes advantage of the specific characteristic of the locale and results in less damage to the urban fabric. Climate responsive design are also known to cost less in terms of energy consumption. To produce the work needed to fulfil this criteria, 3 fundamental skillsets are embedded within the criteria, and we can dissect them as follows:

1) The ability to conduct site analysis to identify the relationship between human to physical geography;
2) The ability to design an urban form / site layout that is informed by the site topography, micro-climate, access and connectivity;
3) The ability to simulate and analyse the impact made by the building design on shading, wind and solar insolation.

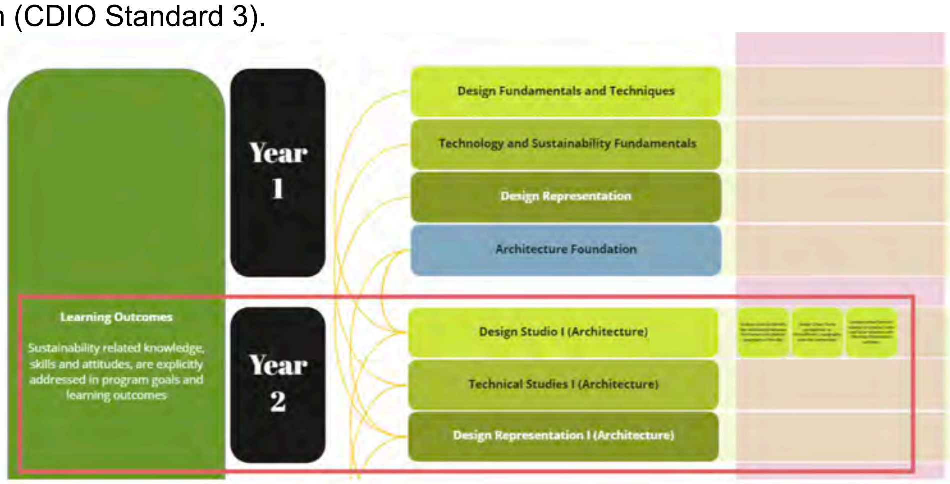
The above skillsets can easily be translated to the following corresponding learning outcomes:

1) Analyse a site to identify the relationship between the human and physical geography of the site;
2) Design urban forms sympathetic to microclimate, topography, and site connectivity;
3) Analyse urban forms in relation to shadow, wind and solar insolation using appropriate simulation software.

In the next section, we shall cover how the above-mentioned learning outcomes translate into learning activities within the Design Studio I (Architecture) course, a 15-week course taken in the second year of the 3-year program.

IMPLEMENTATION IN DESIGN STUDIO I (ARCHITECTURE) COURSE (DS1(A))

The desired learning outcomes are achieved through a horizontal integrated year two curriculum (CDIO Standard 3).



Year Two Integrated Curriculum with Core Courses

Through the vehicle of an integrated project where students design a multi-storey residential development, they simulate professional practice by conceiving, designing, and implementing their projects. This is achieved through incorporating a series of design-implement experiences (CDIO Standard 5) that provide students with the opportunities to apply and contextualise sustainability knowledge, skills, and attitudes with technological advances. Besides acquiring knowledge from DS1(A), students learn technical knowledge and software presentation skills through the support and integral of two other year two courses, namely Technical Study I (Architecture) (TS1(A)) and Design Representation I (Architecture) (DR1(A)) respectively.

As stated earlier, under Green Mark 2021 – GM:2021 Resilience (Re) Section, RE1.3 Contextual Response, the industry practitioners (design team) is to conduct Site Analysis / Simulation at the beginning stage of project design development. In DS1(A), an assignment on Site Study & Analysis is designed and implemented to allow students to go through the same process as practitioners do to simulate industry practices. Students are given a project site in Singapore to carry out the study and analysis in groupwork. This study also enables students to understand the project site and surroundings and prepares them for subsequent design development work of the integrated project. (Please refer to skillsets and learning outcomes mentioned above).

In year two course, emphasis is placed on the study of Singapore climatic influence on building design and user experience. As an integrated curriculum, besides gaining knowledge on climatic influences (sun path, shadow-casting, wind path etc) on building design in TS1(A), students carry out simulation study of these influences on building design using computer software. These design-implement experiences are gained whereby students explore and test out different alternatives / solutions of building orientations on the given project site after the site analysis has been carried out.

In the design of integrated project, design considerations on sustainability will be incorporated and be a key component under the assessment criteria. This integrated approach enables students to gain essential knowledge on sustainability from different disciplines (architectural, structural, environmental etc) and incorporate in the building design project in a holistic manner. Besides acquiring knowledge and skills, students develop awareness on sustainability and climatic impact on built environment. Through critical thinking and problem-solving processes in designing urban forms sympathetic to microclimate, topography, and site connectivity , students thrive being more innovative and solution-minded. Through the integrated curriculum and project, the course strives to change students' attitudes and behaviours towards sustainability.

REFLECTION ON IMPLEMENTATION AND FUTURE PLANS FOR DS1(A)

Based on a self-study approach (Marlon & et al., 2021), the course instructor of DS1(A) (co-author) reflected on students' learning experience whereby students apply and contextualize sustainability knowledge, skills, and attitudes with technological advances. These reflections were informed by students' feedback collected through survey questionaire on their learning and application of knowledge on sustainability. Quantative and qualitative students' feedback were analysed and informed by industry feedback and graduates' survey.

The instructor's reflections and future plan for DS1(A) can be summarised as follow:

1. Keep Courses Up To Date to Align with Development in Global, National and School Initiatives and Plans

Although sustainability has been incorporated in the Year Two program via DS1(A) and TS1(A), there is a need to further update the courses by identifying the essential and relevant knowledge on sustainability to teach in year two courses/modules for students' better learning and understanding at their appropriate level. This is especially important with the recent revision of Green Mark – Green Mark 2021 (introduced in November 2021) and the adoption of a CDIO framework for the entire DARCH program focusing on the aspect of sustainability. This will apply to courses/ modules in the other two years (i.e. year one and three) where the vertical integration across the three years is a key element in the program.

With the global, national and school initiatives/ plans on sustainability being implemented or in the pipeline which constantly impacted the curriculum, it is a challenge for DARCH to identify areas which are appropriate and relevant to be included in the curriculum so as to stay up to date with all the developments. Once the breadth and depth of teaching and learning have been identified, it will be a smoother journey for both course/ teaching team and students.

2. Continue to Plan and Implement a Coherent Course Work for DS1(A) with Relevant Design-Implement Experiences with Real-Life Context and Focus on Sustainability

DS1(A), a 15-week course, was introduced to Year Two cohort in academic Year 2022/2023 Semester One as a revision to a preceding year course named Integrated Project Studio II. (Reasons for revision will not be elaborated here as they are not directly relevant to this Paper).

After Semester One, students went out to industry to do a 22-week internship Program in Semester Two. A survey was conducted after the 22-week internship on students' learning and application on knowledge of sustainability. 84 Students from 5 classes were invited to participate in the survey. 58 responses were collated, and results were tabulated in Table 1 below.

Table 1. Student Feedback Survey *(Showing Percentage of Quantitative Responses)*

AY22-23 (58 responses)			
Questionaire		Yes	No
Q1	During Year 2 of study, I have acquired knowledge on "Sustainability" (e.g. site analysis, climatic response in design, research on sustainable features in precedent study etc) in the module Design Studion I (Architecture) which is useful for my learning	93%	7%
Q2	During internship, I was able to apply the knowledge on "Sustainability" learnt in school to my work	43%	57%
Q3	During internship, I was involved in:		
	Greenmark : To participate in the design processes involved in enhancing the sustainability status of the building (e.g. through the application of the Greenmark, Buildability Score, the usage of relevant software etc)	10%	
	Green Initiatives : To participate in the research, proposing, implementation and documentation of current and future sustainable features in the built environment	19%	
	Others	5%	
	None of the above	72%	
Q4	If your answer for Question 3 is "Others", please write briefly below the area/ areas you were involved.	qualitative feedback summary in discussion section	

Based on the student feedback, observations were made and possible conclusions were drawn and suggested. Please see below for elaboration.

On Students' Learning on Sustainability

93% (about 54 students of 58 responses) gave positive feedback on their learning of sustainability (Q1 of Table 1), informing that they have learnt and acquired knowledge on sustainability. The feedback indicated that students are able to comprehend the course materials on/ related to sustainability and apply the knowledge to the course work through the integrated project/ assignments. It also suggested that students have Integral and meaningful learning experiences through the coordinated integrated project assignment.

In future planning and implementation of DS1(A), aside to imparting knowledge on sustainability through the design-implement experiences in lessons, activities raising awareness on sustainability and encouraging green practices are to be incorporated in the curriculum. The integrated project / assignments will continue to hone students' critical thinking and problem-solving skills. The module aims to reinforce teaching and learning of analytical skills which is currently lacking in students as observed from the site analysis assignment. To enable students to understand the complexity of real-world project, course team will plan for a coherent course work to include all essentials (but not overloaded) with relevant real-life learning experiences for students.

On Students' Application of Knowledge of Sustainability at Work during Internship

As the course aims to allow students to have real life industry experience, the integrated project / assignments are designed to simulate real life industry practice and incorporate requirements practiced in the industry, The survey conducted after students' completion of their 22-week Internship Program aims to find out the relevance of the teaching and learning of sustainability.

Question 2 of the survey (Q2 of Table 1) asked if knowledge on sustainability learnt in school has been applied in students' work during the internship. 43% (about 25 students of 58 responses) gave positive feedback which is encouraging. The result suggested that 1) students are able to identify areas of sustainability in their work and this helps to relate to their learning in school and 2) industry has involved our students in works related to sustainability which will reinforce their learning. The intended and planned design-implement experiences incorporated in DS1(A) have been reinforced during internship.

Question 3 and 4 of the survey (Q3 and Q4 of Table 1) asked for areas of involvement in sustainability to find out more details and specific areas of students' involvement. This is to check the relevance of the course's teaching and learning on sustainability to keep abreast of industry practice and development of sustainable practices in the industry.

As for the next cohort, a feedback survey with more specific questions related to key areas of sustainability will be conducted at end of Semester One before the commencement of internship to prepare students for internship. A second survey will be conducted after the internship program. This will help to close the loop of circle to have useful observation and conclusion.

Validation of DARCH Program by Graduates and Industry

Graduate Feedback

Based on recent Graduate Satisfaction Survey (2021), the program scored well in being up to date according to the requirements of the job market at the point of graduation. On a scale of 4, it achieved a score of 3.14, slightly higher than the polytechnic's average of 3.09.

Industry Feedback

As the DARCH program aims to produce graduates who are work ready for the industry, the program team constantly gets feedback from the industry of our interns and graduates to keep pace with the development of the industry and to make our course relevant. The curriculum is therefore designed and implemented to simulate real life practice. Students are taught relevant and up-to-date software skills. For example, even prior to the introduction of Green Mark 2021, GM:2021 Resilience Section on Contextual Response, DARCH has already prepared the students to do site analysis. Students are able to pick up simulation software to carry out simulation on environmental influence required for site analysis.

CONCLUSION

The embarkment of incorporating CDIO education framework for non-engineering courses, in this instance, DARCH, in the School of Architecture and Built Environment (ABE) is timely. As demonstrated above, the practice of many of the CDIO standards are in place, less only spelt out explicitly. The mapping exercise has also aided the program to re-inspect its alignment with industry needs, especially in sustainability. A tighter engagement with building codes requirement can now be established ensuring a highly relevant graduate profile, capable of meeting the needs of the industry. Moving forward, using the CDIO Standards to improve on the current DARCH curriculum will help ABE path the way to make CDIO's 12 standards, the guiding principles and framework for both its engineering and non-engineering courses for continuous improvement.

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BIOGRAPHICAL INFORMATION

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Yiat Yam Leong is a senior lecturer and an academic mentor of Teaching and Learning Unit in the School of Architecture and the Built Environment at the Singapore Polytechnic. Passionate in teaching and keen in learning, she explores different pedagogies to improve students' learning and to help teaching staff in teaching and learning.

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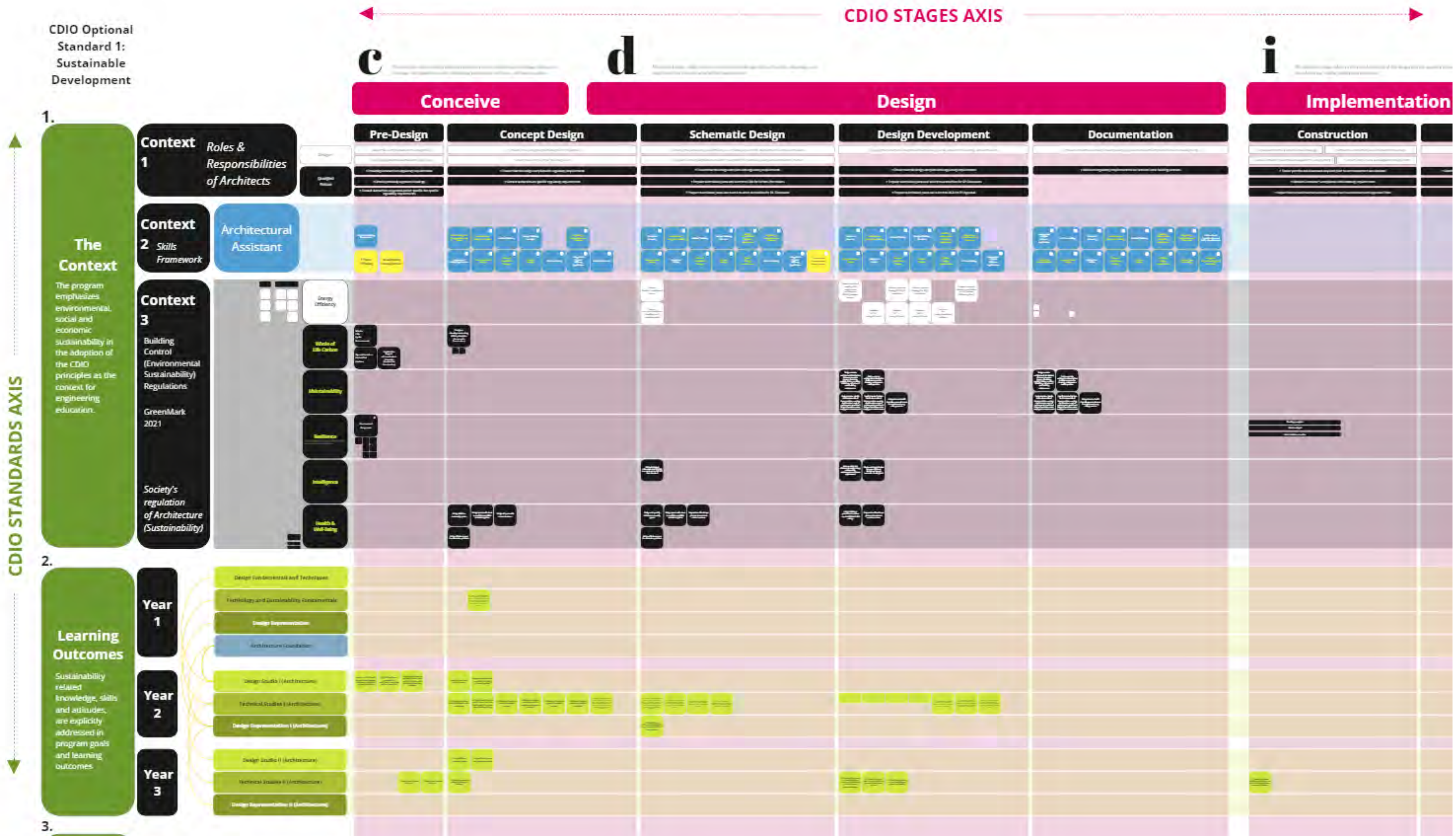
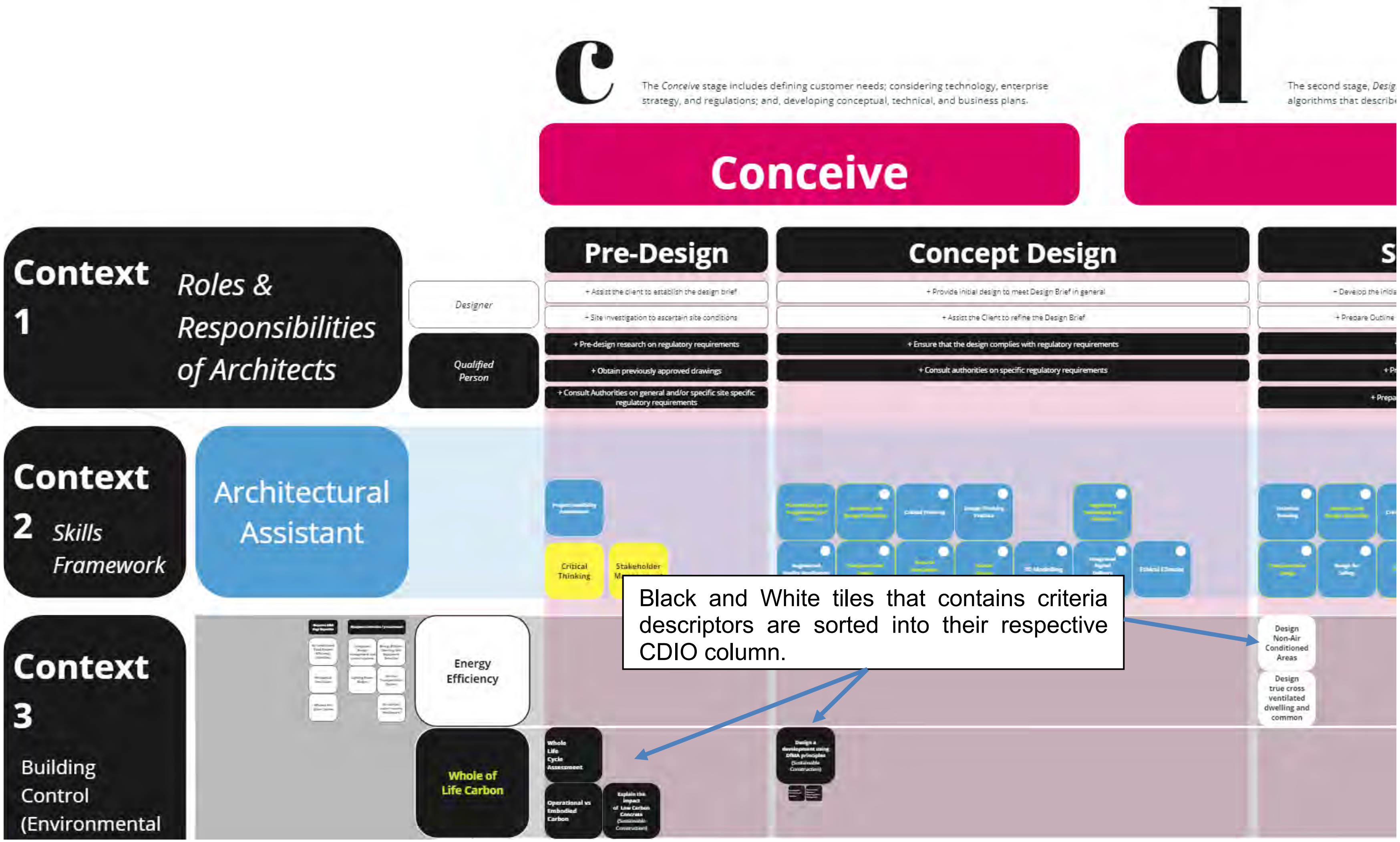
APPENDIX A – CDIO Mapping Chart (Partial)



APPENDIX B – Green Mark Criteria Descriptors in CDIO Mapping Chart



INDUCTION DIAMOND LABS - GIVING EVERYONE AN EQUAL STARTING POINT

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ABSTRACT

Multidisciplinary Engineering Education (MEE) is a specialist department at the University of Sheffield, dedicated to the practical teaching of all the University's engineering students. To provide students a hands-on experience, MEE has a unique building (the Diamond) which includes 15 laboratories offering a spectrum of lab activities to approximately 6000 students.
Students arrive at the University from a variety of different backgrounds. To ensure they start their experimental activities with an equal understanding, we provide different "Diamond Induction Labs". During the first two weeks of the first semester, the students learn how to use hand tools, how to solder, understanding how to interpret data and manage uncertainty and how to do it safely. Three key aspects of this delivery method are considered. Firstly, the principles of laboratory practices are transferable to any engineering disciple. This leads to the second, which is that this delivery is done at scale - with minimal resources over 1000 students, perform the activities each year in a short window of time. Thirdly, it allows for teaching the subjects previously done though lectures using instead practical learning. In the "Danger-lab" we ask students to assess measuring the toughness of chocolate using a mini-Charpy impact tester. The danger is increased by asking the students to also dip the chocolate into liquid nitrogen. During the Measurements lab the students determine the variation in measured flow rates between different forms of instrumentation. While the students gain experience in reading instrumentation and recording data, they also develop an understanding of errors and uncertainty and how they propagate across calculations. We have found that students not only have more confidence in approaching learning in different labs, but they have an increased awareness of hazards in a laboratory, and a better understanding as to how to evaluate the uncertainty within practical work.

KEYWORDS

Introductory Labs, Multidisciplinary. Standards: 4, 5, 6 and 8

INTRODUCTION

About MEE

The Faculty of Engineering at the University of Sheffield offers undergraduate and postgraduate programmes to around 6,700 students in 10 broad disciplines. These are Mechanical Engineering, Aerospace Engineering, Civil and Structural Engineering, General Engineering, Chemical Engineering, Bioengineering, Materials Science and Engineering, Electronic and Electrical Engineering, Automation and Control System Engineering, and Computer Science and Engineering. All of these programmes must include practical activities, such as experiences in laboratories and workshops, to satisfy the accrediting bodies and because without which an engineering curriculum would be lacking.

All of the disciplines taught within the Faculty have overlaps in their content with other disciplines. For example, Mechanical Engineering, Civil Engineering and Chemical Engineering all include fluid mechanics and Bioengineering, Control system and Electrical Engineering all include electrical circuits. It was therefore decided that, when a new building to house teaching laboratories would be built to accommodate a rise in student numbers, rather than new labs being based on and run by discipline specific programmes (for example, the Mechanical Engineering lab), they would be based types of activity (for example, fluid mechanics) and run by a team independent of a specific department. This model has numerous advantages, including the efficiencies that can be achieved through scaling teaching activities to large cohorts of students.

Multidisciplinary Engineering Education is the teaching only academic department in the Faculty of Engineering with the express remit of designing, delivering and assessing the practical activities for all the programs in the shared laboratory and workshop spaces (standard 7) (Petrova, 2021). The team consists of around 50 employees, including academic, technical and professional services staff. In addition to permanent staff, MEE employs hundreds of Graduate Teaching Assistants (GTAs), on an hourly basis, to provide adequate staff-student ratio in large lab classes. Teaching at scale is core to the ethos and operation of the department and opportunities are constantly sought to identify where learning delivered to one cohort could be valuable to another. These principles of finding commonality and teaching at scale have been the guiding principles in the establishment of the departments “induction labs”.

THE INDUCTION LABS

According to CDIO concept, ‘graduating engineers should be able to conceive-design-implement-operate complex value-added engineering systems in a modern team-based environment’ (Crawley, 2001)

In order to address the CDIO model of teaching in a practical environment, the students need building skills (standard 2) which can facilitate their learning in the core engineering disciplines.

The idea of induction labs delivered at the Diamond is to provide the students starting their undergraduate courses with a common framework knowledge (standard 4). The students starting at the University of Sheffield come from different backgrounds and nationalities. At this point it is difficult to categorise their knowledge from the origin of their education and it is much easier to address certain aspects as not covered.

There are different soft skills (group working, presentation skills, etc.) (Audunsson, 2014), that are addressed across the curriculum in the two years of undergraduate courses, however we want to focus as well on more basic knowledge which can facilitate the students' start of their practical work and help staff to focus more on the core technical, personal and interpersonal skills of the practical teaching.

The setup of the Diamond and the large scale of the facility allows the students to have hands-on experience on different techniques. They can build things, operate, and test them; all activities which to be productive must be safe. As per protocol, Risk Assessments are provided for every practical activity but many students starting their undergraduate course in Sheffield may not be familiar with the process and their application.

Health and Safety is an essential part of practical teaching. However, the theory and implementation of H&S traditionally is taught as a passive transmission of information, in fact writing and reading risk assessments is considered a tedious exercise, however essential.

During this short introductory lab, the students are introduced to the risk assessment by writing one for a simple experiment: breaking chocolate at room temperature and using liquid nitrogen. This activity is more engaging, the students apply the steps of writing a risk assessment for a real experiment that they will have to perform straight after.

The Measurements Lab activity is designed to give the students an understanding of uncertainty and demonstrate what is happening in an industrially relevant engineering context. Engineers design and build things that need to function in the real world, and the real world is full of uncertainty. The measurements Lab also introduces the students to the methods engineers use to work with and overcome uncertainty to allow them to do their job of designing and building things.

The scope of this paper is to underline the importance of our Induction labs in students learning and to demonstrate that considering efficiency from teaching at scale (staff, space, and equipment) does not compromise the expected learning outcomes. Also, our introductory labs are focused on active learning that are more effective to use by engaging students in more problem-solving activities. (Dym, 2005)

We will focus our discussion on two Introductory Labs, which are delivered at the Diamond in the first two weeks of the first semester: Danger Lab (Johnson, 2016) and Measurements Lab.

The Danger Lab

The aim of the Danger Lab is for students to design an experimental protocol to measure the impact fracture toughness of chocolate at room and cryogenic temperatures while understanding the risks and hazards of the process (writing a Risk Assessment).

The students investigate the fracture of chocolate. Chocolate is a convenient material as it breaks relatively easily, it is non-toxic and has properties that vary strongly with temperature.

This lab supports the students in manipulating (breaking chocolate at different temperatures), applying (Risk Assessment concepts), analysing and evaluating ideas (how the toughness of chocolate changes at different temperature) (standard 8).

The Danger Lab is run to class sizes of up to 48 students with a staff student ratio of 8:1, comprising 1 academic member of staff and 2 GTAs. The Danger lab is divided into four parts and is timetabled to last 1.5 hours.

The first part is the Introduction to Health & Safety, where the students are shown examples of hazards and how to evaluate their risk using the risk matrix. During this section, the students are shown how to identify the hazards, deciding who might be harmed and how, evaluating the risk and deciding on precautions. The Introduction to H&S is followed by the Experiment description and demonstration; brief description of how to measure the toughness of materials and a demonstration of how to test the toughness of chocolate at room temperature and liquid nitrogen using mini-impact testers (report the capacity) with appropriate personal protection equipment (PPE).

At this point the students should have enough knowledge to write the Risk Assessment for the experiment. They work in groups (4 students maximum per group), and they are encouraged to write the risk assessment collectively by discussing the various hazards and their risks for the experiment. After writing the Risk Assessment (at least 3 hazards), they must complete an experimental protocol for the procedure of testing chocolate at cryogenic temperature, considering the extra personal protection equipment needed and additional setting up steps according to their Risk Assessment.

At the end the students perform the experiment. At this point the students are trained to perform the experiment and are given chocolate and liquid nitrogen. A brief class discussion follows the compilation of the experiment to analyse the class results.

The Measurements Lab

The measurement lab is designed to teach students to recognize and measure uncertainty in measured data and to provide tactics to both manage and communicate to others uncertainty in an experimental result. This is a foundational skill applicable to all disciples of engineering and underpins experimental work conducted in all the degree programmes taught by the faculty.

Students, working in groups of 4 are provided with a hydraulic bench and a variety of water flow measurement devices that use various physical phenomena as proxies to measure volume flow rate. For example, the Venturi meter measures pressure at two locations using a piezometer and, through a combination of the principles of Pascal’s law, continuity and the Bernoulli principle, the volume flow rate can be calculated. These devices are all connected in a hydraulic series to ensure that the flow rate measured by each device is physically identical. The students are then asked to record the measurement and the uncertainty in the raw data collected and consider if, after processing the results, each piece of instrumentation is recording identical results. When there is an inevitable difference in the measurements of each device, students are encouraged to develop a healthy skepticism of the output from any single piece of instrumentation, consider why the results differ from one another and the degree to which uncertainty in the raw and processed results contributes to the discrepancy.

The measurement lab is run to class sizes of up to 80 students with a staff student ratio of 4:1, comprising 1 academic member of staff and 3 GTAs. Session durations are 2 hours. The students usually spend 15 minutes introducing the activity, 45 minutes collecting data and the final hours processing and considering the results. Through many successive repeats of this activity, class management has been honed to an exacting degree. The sessions are typically run 12-15 times in the first week of the University teaching semester, delivering this subject to around 1000 students. Various tactics are employed to scale the delivery, including highly refined printed teaching material that guides students through the work and signposts them to solutions to typically encountered problems, training a pool of graduate teaching assistants (GTAs) to lead and support the sessions, a well produced video to play at the start of the session to introduce the concept of uncertainty and a well designed digital version of the lab available on the VLE to support student that attained or provide an alternative for those students that were unable to attend.

EVALUATION METHOD

In order to evaluate the gain in efficiency from teaching subjects at scale, data on the resources required to deliver the induction labs has been gathered and compared to similar lab classes delivered by MEE (Table 1). Resources consider of note for this analysis are

1. Academic staff and Graduate Teaching Assistant (GTA) contact time during timetables sessions (in hours).
2. Time required for academic staff to train GTAs to deliver the session (in hours).
3. The one off time required to develop the teaching material, including preparation of the lab sheets, planning the session and providing supporting material on the VLE (in hours).

4. The technician time required to set up and take down the lab equipment for the session (in hours)
5. Timetabling efficiency, defined as hours of contact divided by the setup and take down time.

Timetabling efficiency is a proxy to quantify the space use cost of delivering an activity. Space charges, typically charged by a university to academic departments to cover the infrastructure costs such as heating, lighting, cleaning and security, vary between different institutions and can be considerable for city centre campuses. Our definition of timetable efficiency is an attempt to analyse the utilization of space. We run the Induction Labs at full lab capacity (80 students for the Measurements Lab and 48 students for the Danger Lab). However, the full capacity does not only consider an acceptable parameter of space but also allows the students to perform an activity safely and be involved directly with the process and equipment.

For comparison with the danger and measurement induction labs, the resources listed above have also been calculated for two other, non-induction labs run by MEE. The “Ductile to Brittle Transition Temperature (DBBT)” lab has been chosen to compare to the Danger lab and the “Calibration of a flow measurement device” lab, run to 1st year mechanical engineering has been chosen to compare to the measurement lab. These labs have been selected because they are similar experiments to that used in the Introductory labs and are, ostensibly, the same activities lasting the same duration. When taught as induction labs, they are designed for students to meet transferable learning outcomes to a broad range of engineering programmes and when run as non-induction labs they teach subjects specific knowledge to a limited range of engineering programmes. We do not have any data to compare with a situation without Induction labs as we have always run them since opening the Diamond. The percentage difference in the investment of resources, compared to the induction labs, has been calculated based on the per student numbers.

Accessing data in large organizations can be challenging. The centralisation of lab teaching to be delivered at scale justifies the investment of effort to create efficient systems and processes. For example, when GTA allocation of teaching duties is done at a small scale in departments, it is done in a fairly ad hoc way with little process management, as the task is too small to justify optimizing. MEE, in contrast, employs so many GTAs that a streamline system has had to be developed. In addition, MEE’s funding model of contributions from all other engineering departments places it under comparatively larger scrutiny than the income generating departments. As such, a system to plan, manage and audit all teaching activities has been developed. One such system is referred to as your “directory of activities”. As well as providing its primary function, the directory of activities provides a resource of data to be harvested for teaching evaluations such as that presented here.

RESULTS

Table 1. Comparison of resources for teaching at scale

	Danger Lab	Measurement Lab	DBTT	Calibration Lab
Number of students	1368	820	213	194
Total contact time *(hours)*	61.5	30	12.5	8
GTA contact time	140	94	47.5	16

(hours)				
Staff contact time ***(hours)***	123	60	25	16
GTA contact time ***(hours/student)***	0.10	0.11	0.22 (220%)	0.082 (-134%)
Staff contact time ***(hours/student)***	0.090	0.073	0.012 (13%)	0.082 (112%)
Staff training time ***(hours)***	2	2	2	2
GTA training time ***(hours)***	2	16	3	4
Staff training time ***(hours/student)***	0.0015	0.002	0.009 (600%)	0.010 (500%)
GTA training time ***(hours/student)***	0.0015	0.020	0.014 (933%)	0.021 (105%)
Development time ***(hours)***	10	18	15	8
Development time ***(hours/student)***	0.007	0.02	0.07 (1000%)	0.04 (200%)
Technician time ***(hours)***	12	2	50	4
Technician time ***(hours/student)***	0.0088	0.0024	0.23 (2590%)	0.021 (875%)
Timetabling efficiency	74%	94%	20%	60%

DISCUSSION

Work loading of staff is of significant concern in the UK HE sectors, and one of the primary causes for recent industrial actions by unions. Finding innovative methodologies to reduce staffing reduces staff time input without compromising the student experience is of paramount importance. As expected, the result shows that by scaling teaching, in most cases the amount of contact time required by staff and GTAs was reduced. The effects are less noticeable in the required training and development time. While more teaching would typically require more contact, activities that need to be completed once regardless of the amount of teaching become much more efficient when scaled up. The most dramatic results are seen in the technical and space resources. When equipment needs to be set up and taken down between different activities, staff are required, and the equipment/room cannot be used for other purposes. By running many sessions sequentially, this wasted can be substantially reduced.

The initial development of these intro labs was a lengthy and trial and error process. We had to address the impact on staff and facilities to deliver a back-to-back activity to such an impressive number of students in a short period of time. In retrospect, it has been a successful journey. At the start of each academic year, we need to train the new GTAs and staff which is still more effective compared to the non-induction labs training.

We have not considered in the comparison the turnaround time. For the Intro labs, which run during the first two weeks of the first semester, the turnaround time is practically zero because we run lots of the same lab back to back in the same space. In comparison the core labs across the semester are scattered due to timetable constraints and the same lab can be delivered once a week across different weeks.

For a number of reasons, also the equipment and consumables costs have not been included as part of the evaluation. Primarily, this due to the difficulty in determining to what extent lab equipment contributes to individual activities. Many pieces of equipment found in laboratories are considered part of the standard facilities and so are present regardless of the activities conducted. Consumables costs tend to be negligible in comparison to staffing costs. However, as is quantitatively shown with other resources considered in the results, teaching at scale encourages the reduction of costs for equipment and consumables. If a single use sample costs £10, this is of little concern if it is used by 10 students. If it is used by 1,000 students, the investment of intellectual effort in considering an alternative sample or teaching method could be used to fractionally reduce the unit price.

The labs do not have a formal assessment during or after the session, the students have to turn up and get involved. This setup makes the lab more relaxed and fun, however it may be considered of little importance without any form of assessment. In practice, the students are observed when they undertake the labs - so a form of formative direct assessment takes place, considered more advantageous in a practical environment (Reiss, 2015).

The aim of the Danger Lab is for students to understand how to write the RA and how to use it. The aim of the Measurements lab is for students to recognize and measure uncertainty in measured data. As a result, the Intro Labs are not directly linked to the specific module outcomes. They are more generic and basic skills which will be indirectly assessed downstream at some point during the practical sessions in the context of a broad range of engineering programmes.

The Intro Labs are flexible, practically you can take the danger lab anywhere. We have used this lab for different contexts, such as staff training or outreach activities (mostly schools). The Measurements lab is restricted to the equipment located in the Fluids Lab in the Diamond at the moment, however the same concepts and calculations can be transferred to any other measurement equipment.

We have demonstrated that we can run induction labs in an efficient and scalable way without compromising students learning. This has a positive effect on staff load and space usage. The students learning outcomes cannot be directly and numerically proved as we do not have purposely a summative assessment for these labs. The aim of the Induction labs is to make the students aware of how to work safely and how to analyse measurements and uncertainty.

We have ‘checking points’ during the rest of the semester, which allows us to remind the students of what they have done during the Induction labs and apply the knowledge to the core labs. Almost each lab activity involves hazards, risks, measurements, and errors. The students must use the Risk Assessments provided to answer the prelab quizzes based on the hazards and risks before the lab session. While taking measurements the students must do it correctly to a specific accuracy of the equipment used and consider the uncertainty involved and process any discrepancies.

CONCLUSIONS AND FURTHER WORK

In conclusion the Diamond Intro Labs have been a success from a point of view of student participation and engagement, staff workload and delivery efficiency (timetable efficiency in Table 1). These labs are fun in an instructive way, giving the students an equal starting point regarding safety and measurements techniques, easy to set up and provide training for.

We want to do more in providing students with opportunities to acquire skills that are not directly connected with module outcomes and do it without the pressure of pass or fail. During core labs the students are more focused on the results and the learning outcomes of an experiment and do not have a perception of the path they have used to get there.

We in MEE are looking to implement a set of practical skills opportunities spread across all the academic year to shift the focus from core knowledge (theoretical) and concentrate more on practical skills (basic CAD, robotics-Turtlebot, intro to E&C, basic python), which can be used in conjunction during their course but also for working future experience.

Also, it is worth mentioning that these labs are free to the public and anyone interested in developing any of these skills for their courses.

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BIOGRAPHICAL INFORMATION

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CONCEIVING, DESIGNING AND IMPLEMENTING THE MECHANICS TEACHERS SOCIAL CLUB

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ABSTRACT

As part of the Delft University of Technology's (TU Delft) bachelor programmes, mechanics courses are provided across 7 out of its 8 faculties by more than 70 mechanics lecturers. Yet, mechanics is considered a difficult subject to teach, with lecturers reporting that they have limited time and resources to assess and improve their teaching practice. Moreover, these lecturers are seldom connected. The lack of collaboration and exchange between the mechanics lecturers has resulted in limited peer-to-peer support and hindered the development of shared mechanics teaching competence. To tackle these challenges, the PRogramme for Innovation in MECHanics education (PRIMECH) was launched at TU Delft in 2021. In this paper, PRIMECH's solution is discussed: the introduction of the Mechanics Teachers Social Club, an inter-faculty Community of Practice (CoP), built around the shared domain of interest of teaching mechanics and improving students' conceptual understanding. The CoP aims to enhance lecturers' awareness of best teaching practices and foster collaboration on new educational projects. Within this CoP, lecturers are encouraged to share teaching materials, discuss pedagogical approaches, and share advice towards achieving this goal.

KEYWORDS

Community of Practice, Enhancement Teaching Competence, Mechanics, User-Centred Design, Standards 1, 2, 4, 7, 8, 9, 10, 11, 12

INTRODUCTION

Mechanics is a core subject of study in most bachelor curricula of engineering, architecture and industrial design programmes. By mechanics we refer to the disciplines that study the effects of loadings on physical bodies and structures, such as statics, dynamics and mechanics of materials. These disciplines provide fundamental knowledge for the development of product-, process-, and system-building skills. Therefore, as part of the Delft University of Technology's (TU Delft) bachelor programmes, mechanics courses are provided across seven out of its eight faculties by more than 70 mechanics lecturers. mechanics courses are provided across 7 out of its 8 faculties by more than 70 mechanics lecturers.

Given the wide spread of mechanics disciplines across campus, the TU Delft Central Student council initiated the PRogramme for Innovation in MECHanics education (PRIMECH) in 2020. The PRIMECH project was then further supported by the Education and Students Affair office of TU Delft, which dedicated extra Nationaal Programma Onderwijs (NPO) funding to the project (Minister van Onderwijs, Cultuur en Wetenschap, 2023). The PRIMECH project was officially launched at TU Delft in October 2021 and funded till August 2024. Afterwards, the project is expected to be self-sustained, and the initiating team will be dissolved.

The goal of the Student Council in initiating the PRIMECH project was to replicate the success of PRIME (Programme of Innovation in Mathematics education; Cabo & Klaassen, 2018; Cabo & Klaassen, 2019) in the field of mechanics courses. The PRIME project, which began in 2014, aimed to develop an alternative method of teaching mathematics to engineering students. Prior to 2014, mathematics courses were already taught by many lecturers belonging to the same group, the Delft Institute of Applied Mathematics (DIAM). With the implementation of PRIME, these lecturers became part of a larger project team. Together, they develop teaching material, and they maintain and teach approximately 45 courses belonging to various TU Delft bachelor programmes.

During the initial stages of the PRIMECH project, it became evident that replicating the PRIME approach was not feasible. Unlike mathematics education, the teaching of mechanics is decentralised, with each faculty responsible for its own mechanics curriculum. The current TU Delft organisational structure is based on each faculty being a completely independent entity, responsible for its own research and educational activities. Therefore, centralising mechanics education would require a structural reorganisation across multiple faculties, resulting in a significant amount of time, resources, and buy-in from various stakeholders. Thus, it was deemed a high-cost and low-priority change to implement.

Consequently, the PRIMECH team, initially comprising an educational project manager, an educational advisor, and a system architect, re-evaluated the project's goals while retaining the interfaculty character of the initiative. The PRIMECH team conducted an exploratory analysis to identify the underlying needs and opportunities for innovation. Based on the findings, the team proposed the introduction of the Mechanics Teachers Social Club, an interfaculty community of practice (CoP), built around the shared domain of interest of teaching mechanics and improving students' conceptual understanding. This ongoing intervention aims to promote community-based professional development, in accordance with CDIO standard number 10: Enhancement of Faculty Teaching Competence. This standard calls for creating a supportive environment that encourages and enables faculty members to continuously improve their teaching practices, leading to better quality education for students (Malmqvist, Edström & Rosén, 2020).

The enhancement of faculty teaching competence is widely regarded as a major challenge in the implementation of the CDIO curriculum or any active learning approach (Loyer & Maureira, 2014). The Mechanics Teachers Social Club is a key example aimed at enhancing the teaching competence of faculty members with an interfaculty approach. This paper presents the first three phases of the ongoing PRIMECH project, namely Conceiving, Designing, and Implementing, along with the initial steps and plans for the Operating phase. While it is not yet possible to accurately measure the impact of the intervention on students' learning, the aim of this paper is to share insights and experiences gained thus far, with the hope of providing useful information to others attempting to implement similar projects.

CONCEIVING

As replicating the PRIME approach was not feasible, the PRIMECH team had to re-scope the project. The team began by analysing the initial requirements, which included the intervention being inter-faculty, aiming at improving mechanics education at TU Delft, not requiring a structural reorganisation within the university faculty, and being led by the PRIMECH team until the end of academic year 23/24. Thereafter, the aim is for PRIMECH to be self-sustainable. To further define the project requirements, the PRIMECH team conducted an exploratory analysis of the mechanics educational system, following the Design-Based Educational Research approach (McKenney & Reeves, 2018). The goal was gaining a comprehensive understanding of the educational context and potential areas for improvement, as well as determining and managing the expectations of stakeholders.

Exploratory analysis

In the exploratory phase of the study, two data collection methods were utilised: unstructured interviews and document analysis. More than 30 interviews were conducted with various stakeholders, including teachers from three distinct faculties, the student council, faculty study associations, learning developers, academic counsellors, directors of education, and directors of studies. The questions asked were aimed at gaining a comprehensive understanding of the educational context and desired outcomes, specifically with regards to the current teaching methods and systems in place in the different faculties, the challenges faced by the mechanics teachers, and the current status of student learning in mechanics.

In the document analysis, a comprehensive review of various written materials was conducted, including the university's vision on education, the organisational structure, materials from the mandatory teaching qualification course, mechanics course descriptions, outlines, and slides, as well as statistics on student performance in previous years, and students' feedback on the mechanics education they received. The insights gained from this analysis were integrated with the outcomes from the interviews to form a comprehensive picture of the mechanics education context.

The exploratory analysis yielded several key findings, such as the stakeholder map of the university's organisational structure, a comprehensive list of TU Delft's bachelor mechanics courses and respective teachers, a detailed representation of the teaching system, personas, and the problem statement. However, to preserve privacy and ensure brevity, certain findings, such as the stakeholder map, the list of mechanics courses and teachers, and the in-depth personas were not included in this paper.

Representation of the teaching system

At TU Delft, mechanics is taught across seven of its eight faculties, with over 70 mechanics lecturers providing instruction. These lecturers are generally affiliated with the faculty in which they instruct. Mechanics courses are present in various bachelor's degree programmes, including Civil Engineering, Mechanical and Maritime Engineering, Aerospace Engineering, Applied Physics, Architecture, Geoscience, Electrical Engineering, and Industrial Design. In many cases, these programs offer mechanics as a series of sequential courses and often link mechanics courses to design projects. The curricula of Aerospace, Civil, Mechanical, and Maritime Engineering are most closely aligned in terms of mechanics instruction. Despite the similarities in the theoretical content taught across faculties, the specific applications and contexts of this content vary. The pedagogical approach and delivery strategies used by mechanics lecturers vary as well, ranging from traditional lecture-style teaching to flipped classroom environments. Additionally, the number of credits awarded for completing a mechanics course differs among faculties.

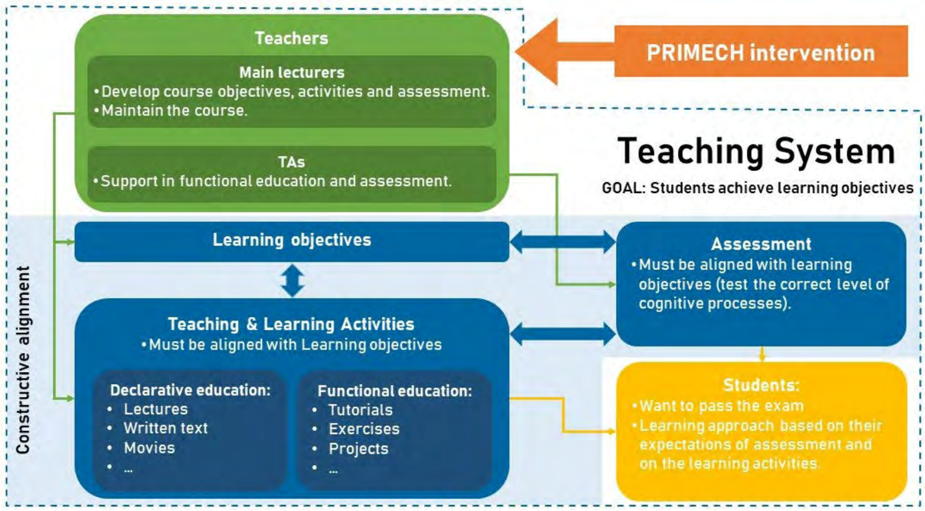
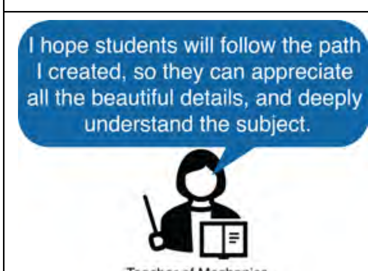
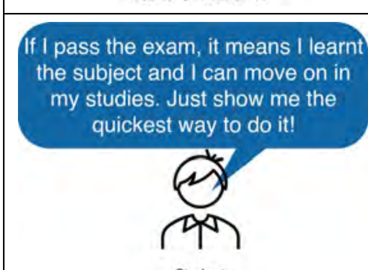


Figure 1 - Teaching system of bachelor-level mechanics courses at TU Delft

The teaching system at the course level has been visually represented in Figure 1. This model displays the use of the constructive alignment triangle as the main educational principle in developing courses at TU Delft (Biggs, 1996). The principle of constructive alignment is centred around the idea that teaching and learning should be designed in a manner that facilitates the achievement of desired learning outcomes by students. Figure 1 highlights the impact of the different components of the triangle on students' understanding and study attitude and underscores the primary role of teachers in teaching as well as shaping the course content, structure, objectives, methods, materials, and assessment.

Personas

Table 1 – Simplified personas of the intended users of the intervention

Persona	**Frustrations, needs and wants**
	**The mechanics teacher** • Highly values the job of teaching to the next generation of engineers, they want to be good at it. • Has limited time, balancing education and research duties. • Wants to collaborate and share material with other teachers and align their courses, • … but wants to keep their teaching freedom.
	**The first-year mechanics student** • Has a “hectic schedule” between courses and extra-curricular activities. • Wants to pass the exam with minimum effort, still has a “high school” study mentality. • Tends not to understand fundamental concepts properly. • Sees their curriculum of studies more as an obstacle course than a learning experience.

PRIMECH created personas to summarise the findings from the interviews conducted and to insure the alignment of the final solution with the identified users' needs. A simplified version of the personas for mechanics teachers and students can be found in Table 1; however, as noted above, the detailed personas cannot be shown due to privacy concerns. The personas were developed based on different teacher types, including those hired as full-time lecturers, tenure trackers, and a range of professors from assistant to full. From the interviews, it emerged that the teacher's role influences their time availability for teaching and their level of experience and willingness to learn from and share their experience with others.

Problem statement

Teachers reported difficulties in creating an effective course structure, in incorporating active-learning activities, and in developing appropriate assessments, particularly with large class sizes. They also reported limited time, resources, and discipline-specific support to assess and improve their teaching practice. Moreover, these lecturers are seldom connected within and across faculties. This decentralisation of mechanics instruction resulted in a lack of peer support, hindering the development of shared mechanics teaching competence and leading to a sense of isolation and duplication of efforts: teachers feel like they are often "reinventing the wheel" when developing teaching material and activities for their mechanics courses.

Insufficient conceptual understanding in mechanics was identified as a major challenge for students, who often resort to memorisation of formulas rather than forming a deeper understanding of core mechanics concepts and their interrelationships. Poor study attitudes, including a lack of metacognitive skills, self-directed learning, and limited awareness of desired learning outcomes, were also observed, resulting in low passing rates for mechanics courses. Furthermore, students often struggle to transfer and retain learned mechanics content, causing frustration among subsequent course instructors.

PRIMECH objectives

PRIMECH's primary objective is to innovate mechanics education at TU Delft. Based on the insights gained in the exploratory analysis, PRIMECH decided to intervene within the teaching system by collaborating with the teachers, as illustrated in Figure 1. Accordingly, PRIMECH has further defined its objectives in a two-fold manner:

1. Providing (domain-specific) support for the mechanics teachers:
    - Facilitating the alignment between mechanics courses within each Bachelor programme.
    - Promoting the interfaculty collaboration and exchange of material, good practices, and peer-to-peer support.

    In the long term, this support would aim at innovating the mechanics teaching system and, consequently,
2. Helping more students adopt a deep approach to learning:
    - To better understand and acquire mechanics concepts.
    - To help the development of an effective studying mentality.

DESIGNING

After defining the project objectives, a co-design process was initiated to delineate the intervention strategy. Three statics teachers from different faculties (Mechanical and Maritime Engineering, Aerospace Engineering, and Civil Engineering) were selected to participate in the co-design process. This is as statics is taught similarly in the first quarter of the first-year bachelor programme in these faculties and served as the students' initial exposure to engineering after high school. Five workshops were conducted over five months to explore the solution boundaries further. Figure 2 showcases the statics teachers during two of the workshops.

Figure 2 – Statics teachers during two of the PRIMECH workshops

The first step in the co-design process was establishing a shared vision for the intended learning outcomes of the statics courses among the participating teachers. This allowed for an in-depth examination of the course components. Then, the teachers identified possible improvement areas, such as teaching for conceptual understanding, promoting self-directed learning and accommodating diverse learning paces. The teachers found that they were spending a significant amount of time developing teaching materials and assessments, feeling like they were “reinventing the wheel”, leading to a decision to share resources and investigate the use of an online repository tool. It also became apparent that the frequent co-designing meetings were alleviating the sense of isolation experienced by teachers, allowing them to engage in meaningful discussions with their peers. Consequently, PRIMECH decided to extend these activities to all TU Delft mechanics teachers by implementing a CoP: the Mechanics Teachers Social Club.

Community of Practice (CoP) and community-based professional development

“Communities of practice are groups of people who share a concern or a passion for something they do and learn how to do it better as they interact regularly” (Wenger-Trayner, 2015).
CoPs typically form around a shared domain of interest and are characterised by social interaction and collaboration between members (community) to improve their expertise in a particular area (practice). These groups are frequently utilised to support community-based professional development for teachers. Although the CDIO community has previously addressed this intervention through various publications, such as Kilstrup, Hellgren, & Andersson (2011) and Cárdenas, Martínez, & Muñoz (2013), there is still a need for further investigation into its effects and implementation.

PRIMECH CoP: the Mechanics Teachers Social Club

The PRIMECH team took the role of initiating the Mechanics Teachers Social Club with the responsibility for organising and operating the community for the first two years, as well as fostering ownership of the CoP among the teachers with the aim of promoting its continuation after the PRIMECH central team dissolves. The CoP was designed around the shared domain of interest of teaching mechanics and improving students' conceptual understanding, with all TU Delft Bachelor-level mechanics teachers as intended members. The CoP was designed on two levels in alignment with PRIMECH objectives: 1. supporting teacher professional development (teacher level) and 2. collaboration on new educational projects aimed at improving students' conceptual understanding and studying mentality (student level).

To achieve these objectives, it was planned that the CoP activities should include networking events and guest expert events. The networking events aim to encourage collaboration and discussions among teachers, leading to a rethinking of the learning objectives, course structures, learning activities, and assessments in mechanics courses, as well as to new teacher-led mechanics education projects. The guest expert events are designed to share information about teaching tools and provide a platform for members of the community to highlight their educational initiatives. Additionally, a Microsoft Teams group was established, providing a virtual space for teachers to meet, share material and discuss their teaching practices across faculties. It was decided to constantly monitor the CoP success based on the perceived value it added for teachers. To do so, surveys are conducted after each event to assess if PRIMECH is on track towards achieving the various goals outlined in this paper.

PRIMECH could not mandate participation in the CoP for TU Delft bachelor-level mechanics teachers, so they developed a communication strategy to encourage teachers to join. The strategy included sending a monthly newsletter to all mechanics teachers and using a LinkedIn page. The aim of the newsletter is to keep the community informed of the latest CoP developments and encourage their participation, as clearly stated in the newsletter header shown in Figure 3. The monthly newsletter was designed to feature the “teacher-of-the-month” column, a series of interviews with active members of the community. This serves multiple purposes, as it demonstrates the value of being in the CoP to non-participants, it creates a reputational platform that values teachers for their teaching competence, and it fosters a sense of ownership through teacher integration. The LinkedIn page was created to increase the Social Club's visibility by taking advantage of the vibrant LinkedIn network that extends throughout TU Delft.

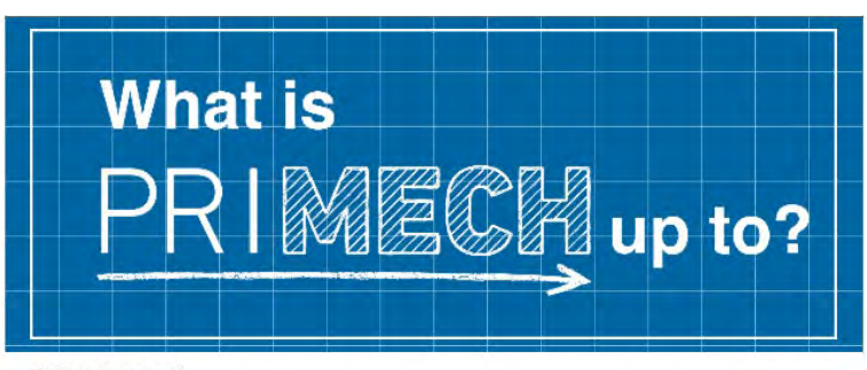


Figure 3 – The header of PRIMECH Newsletter

IMPLEMENTING

In June 2022, PRIMECH launched the Mechanics Teachers Social Club by organising the first networking event, a social lunch where all TU Delft mechanics teachers were invited, with the aim of convincing them to join the CoP. Strategic partners were also invited to inform them of PRIMECH's results up to this point and collect their feedback. Around 25 people participated in the event. Through the three hands-on activities displayed in Figure 4, attendees had the opportunity to get to know each other, discuss mechanics education in TU Delft Bachelor programmes and the challenges faced in teaching this subject.

Figure 4 Hands-on activities of the mechanics teachers social lunch event

The hands-on first activity, "After all, what is Mechanics really all about?" challenged attendees to define the essence of mechanics in just one sentence. The second activity, "Mapping Mechanics," involved creating a mind map of the fundamental concepts of the discipline, providing a comprehensive view of mechanics, and helping attendees discuss how the concepts are interconnected. The third activity, "Teaching Mechanics," was a plenary discussion centred on the challenges of teaching the fundamental concepts of mechanics. These hands-on activities served as a networking platform, promoted collaboration between teachers, and helped the development of a common vision on mechanics education at TU Delft.

During the final plenary session, teachers also expressed their enthusiasm for joining the Mechanics Teachers Social Club. The teachers were determined to continue working together to develop a shared vision for mechanics education and new educational projects. To achieve these goals, they agreed to meet every six weeks during lunch breaks in the upcoming academic year. They expressed interest in delving deeper into the fundamental concepts and skills of mechanics, with a focus on the challenges and best practices of teaching them. In addition, the teachers committed to continuing the development of the open repository of mechanics learning materials.

OPERATING

In the 2022/2023 academic year, the Mechanics Teachers Social Club is operating as planned. As of April 2023, the club has published fourteen monthly newsletters that feature reports on CoP activities, "teacher of the month" interviews, and insights into useful educational theories. Four key activities have been hosted, including 1) the co-development of concept maps using an in-house TU Delft concept-mapping tool to aid students in navigating their learning, 2) a networking event to gather teacher feedback and aspirations for the community, 3) a guest-expert lecture on designing and implementing in-class demonstrations for mechanics, and 4) a lecture by two members of the community sharing their approach to formative assessment and their insights from creating a shared question bank using an e-learning assessment tool.

Through the after-event surveys, teachers have reported that they are eager to implement the new discussed strategies in their courses and that they have been meeting new colleagues, with some teachers even beginning to collaborate on new educational projects without the direct involvement of the PRIMECH core team. These preliminary results are encouraging and in alignment with the PRIMECH objectives.

DISCUSSION AND CONCLUSIONS

When the preliminary goal for PRIMECH was deemed unachievable, the project had to be re-scoped. During the conceiving phase, PRIMECH conducted an exploratory analysis across faculties to gain a better understanding of the educational context. In retrospect, approaching this phase without a preconceived solution in mind was the right decision. This allowed the PRIMECH team to thoroughly analyse the contextual needs and realise the importance of collaborating with teachers for the success of the intervention. During the designing phase, PRIMECH held frequent workshops with a small group of statics teachers to design the intervention project collaboratively. Based on the outcomes of these workshops, PRIMECH identified the students' insufficient conceptual understanding of mechanics as a potential domain for developing a CoP, which would provide (domain-specific) support for the teachers and promote the implementation of new teaching strategies to help more students adopt a deep approach to learning, in accordance with the two PRIMECH objectives. In June 2022, PRIMECH launched the Mechanics Teachers Social Club, and several mechanics teachers joined the CoP. The development of the Mechanics Teachers Social Club took a total of 9 months, starting from the conceiving phase to the implementing stage. Since September 2022, the club has been operating according to plan. The team's future focus is to foster even more ownership and active involvement in the CoP operations among teachers, to ensure the sustainability of the club after the PRIMECH team dissolves.

In conclusion, the Mechanics Teachers Social Club is tackling the need for innovation in mechanics education at TU Delft by fostering collaboration and enhancing the teaching competence of mechanics teachers, in accordance with CDIO Standard 10. The teacher-centred approach allowed the team to develop a solution that is valued by the teachers and has already shown promising results in innovating their teaching practice. The authors believe that the insights and experiences shared in this paper can be of great value for universities and faculties looking to enhance the teaching competence of their members by implementing a CoP.

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BIOGRAPHICAL INFORMATION

Marta Gavioli holds an MSc degree in Electrical Engineering, and she is currently a PhD candidate in the field of Engineering Education. Her research project focuses on conceptual understanding of mechanics. Since October 2021 she leads PRIMECH: PRogramme of Innovation in MECHanics education at TU Delft, a university-wide initiative to innovate mechanics education together with the mechanics teachers. As such, she is involved in developing tailored educational projects, workshops and events, and coordinating a growing group of people involved in the process.

Grant Penny holds an MA degree in Online and Distance Education. He is an educational advisor, working at TU Delft in Education and Student Affairs on educational innovation and student success. His current focus areas include transferrable skills, peer-to-peer development, and future education policy. Since 2022 he has been working on PRIMECH: PRogramme of Innovation in MECHanics education at TU Delft, a university-wide initiative to innovate mechanics education together with the mechanics teachers.

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EVALUATING THE USE OF ITP METRICS IN SUPPORTING TEAMWORK

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ABSTRACT

Learning to work within a team is an essential part of an engineering student's education. However, teamwork is not something that can be easily taught; students are often expected to develop a whole range of attributes and skills that come under the umbrella term 'teamwork' simply by participating in team activities. The School of Engineering, University of Liverpool is addressing recent student feedback that has revealed that students would benefit from, and be comforted by, more support in developing their interpersonal communication and teamwork skills. To enhance the provision of such support from instructors, the authors have deployed ITP metrics, a suite of online tools that has been developed by The Individual and Team Performance (ITP) Lab at the University of Calgary. In particular, this paper focuses on the use of; Team Contracts, a document that outlines expectations and team norms; Personality Assessment, a tool that builds awareness of personality factors and encourages reflection; Conflict Management Styles, a tool that explores personal styles and how they influence interactions with others and; Team Health Audit, a team diagnostic tool that aims to improve team performance. This paper describes how these tools were deployed and the associated learner benefits. In particular it explores further questions relating to; students' perceptions of using the tools; the barriers to engagement with the tools; and the alignment of these tools with different learning activities, at different levels of study. The paper finds that although the tools can support student development, activities that make use of the tools require more planning and development than initially assumed.

KEYWORDS

Teamwork, Skills Development, Reflective Practice, Standards 3, 5, 7

INTRODUCTION

Teamwork is a fundamental skill that graduate engineers are expected to master by the time they enter the engineering profession. This is reflected in the importance placed on this skill set by accrediting bodies, professional bodies, employers; and common benchmark statements such as the CDIO Syllabus. In the authors experience, most students entering university to study engineering have no significant experience in completing projects as part of a team and often lack the soft skills needed to successfully participate in team activities. However, training students to develop these soft skills can be difficult for instructors more experienced in teaching technical disciplines (Andersson 2009) and who may be unfamiliar with employing teaching strategies outside of the traditional didactic methods that are often needed for soft skills development (Varkey et al. 2009).

Although soft skills now have a more prominent role in engineering syllabi, the development of soft skills in engineering education has been undermined by the lower status given to them over the previous decades (Male et al. 2009). This is reflected in the common 'hands-off' approach taken to teaching soft skills in engineering; put students into a team with only a rudimentary introduction to teamwork, give them a task and, assume that when conflicts arise students will deal with the issues themselves thus, learning from the experience (Usprech & Lam 2020). But this approach often fails as participation in team activities alone does not give students an understanding of effective behaviours and approaches; soft skills training requires proper support to ensure graduates are equipped to enter the engineering profession (Larson et al. 2016).

The literature from CDIO collaborators does offer examples of how to implement projects were students are required to work as a team and provides plenty of pedagogic reasoning for why implementing it can be of benefit (for example; Huet et al. (2008), Anderson (2009), Martins & Ferreira (2016) and Ling & Nengfu (2021)). However, there appears to be a scarcity in the literature that discusses how to support, encourage, and optimise student learning once a team activity has been introduced or what specific strategies instructors should implement when students begin to experience difficulties due to their inexperience. An example of this can be seen in a paper from Tedford et al. (2006) that details the experiences gained from running a team activity. A rationale for using project-based learning and team activities as a tool to improve soft skills is given, pedagogical approaches are documented and the paper presents both positive and negative feedback from students. However, no indication is given on how the instructor intended to address the negative feedback and support the students as they acquire the necessary skills to navigate the difficulties of teamwork.

MEng students graduating from the School of Engineering have been shown, through observation by academic supervisors, feedback from employers and from end of module feedback surveys, to possess the necessary skills to comfortably navigate professional level team environments. The pre-professional, real-world Capstone projects they work on in their final years of study have been shown to provide the necessary environment and support to enable them to develop the relevant skills (Topping & Murphy 2022). But teamwork issues can still arise in these Capstone projects and feedback has shown that the learning journey of a first year student getting to graduation still requires further support and guidance. This paper aims to explore how well established team activities can be further developed to offer students more support and guidance in developing interpersonal communication and teamwork skills.

TEAM ACTIVITIES AT THE SCHOOL OF ENGINEERING

All undergraduate programmes in the School of Engineering are built around a succession of teamwork experiences; increasing in duration and complexity, as students progress through the four year programme. Most of these activities are part of project-based courses, but students frequently work in groups on other tasks such as technical writing, ethics, and scientific problem solving. This study focusses primarily on design and design-build-test learning experiences. The figure below summarises the central spine of team activities in the MEng Mechanical & Aerospace programmes.

Teamwork Experience	Team Contracts	Personality Audit	Conflict Management	Team Health
Novice	ENGG111	ENGG111		
Intermediate	MECH212	MECH212	MECH212	
	AERO220	AERO220	AERO220	
Experienced			MECH327/431	MECH327/431
			AERO321/420	AERO321/420
			AERO401	

ENGG111: ***Introduction to Engineering***

- 8 week DBT Activity
- 1st Year: 5-7 per team

AERO220: ***Aerospace Engineering Design***

- 24 week Design challenge
- 2nd Year: 6 per team

MECH212: ***Mechanical Engineering Design***

- 24 week Design challenge
- 2nd Year: 6 per team

MECH327/431: ***Mechanical Capstone Project***

- 48 week Real-world design challenge
- 3rd & 4th Years: 3-15 per team

AERO401: ***Flight Handling Qualities***

- 12 week Real-world design challenge
- 4th Years: 6-8 per team

AERO321/420: ***Aerospace Capstone Project***

- 24 week Real-world design challenge
- 3rd & 4th Years: 6-8 per team

Figure 1. Primary Team Activities and Deployment of ITP Metrics tools

Historically, our approach to developing teamwork skills in our students has been one of immersion rather than formal instruction. In other words, students have been tasked with team based activities with little preparatory teaching of theory – instead learning through repeated, often painful experiences and guided reflection on those. At the heart of this approach is close support and supervision from academic staff as students complete their projects. Each student team has a 10 minute coaching and support session per week in Year 1, rising to 20 minutes in Year 2, and several hours close supervision in Year 3 & 4 Capstone projects. This approach has been optimised over 12 years and has been effective as proven by testimony from our graduates and their employers.

However in recent years formal evaluation feedback has revealed that students would like more formal instruction to prepare for team-work. They acknowledge the effectiveness of our existing approach, but they suggest they would benefit from more preparatory coaching and improved tools to support their reflective practice. To this end we developed a pilot project to explore the deployment and effectiveness of ITP Metrics.

PROPOSED INTERVENTION - ITP METRICS

ITP Metrics is an online platform that has been developed by The Individual and Team Performance (ITP) Lab at the University of Calgary. The platform can assess, track and report on individual and team metrics and provide diagnostic feedback and structured resources to support and improve individual and team performance (itpmetrics.com). The platform is browser based and free to use, providing assessments in five areas: Team Health, Peer Feedback, Conflict Management, Personality, and Leadership. An assessment requires a participant to complete a questionnaire that presents a series of statements which they respond to using five-point Likert scale answers. Questionnaires should take around 10-15 minutes to complete.

On completion, participants will be presented with a detailed personalised report, auto generated based on their answers, that places their results in a relevant context and provides insight into their competencies.

Two of the authors attended a workshop run by Dr Thomas O'Neill, founder of the ITP lab, at the recent international CDIO conference to investigate the potential of utilising the platform to support their efforts in improving students teamwork skills. As noted above, recent feedback from end of year surveys had demonstrated that new strategies were needed to support student learning and attendance of the workshop was aimed at exploring a potential solution. During the workshop the functionality of the ITP metrics tools were described and a demonstration given of the Conflict Management tool, with participants invited to complete short self-assessment and then discuss their subsequent results.

The study by Usprech & Lam (2020), although not conclusive, shows that there may be benefit to utilising these tools. Jamieson and Shaw (2018) report a preference for using ITP over a similar platform (CATME) and report that it can support overall team development with functionality that allows students to reflect on their own strengths and weaknesses which can, in turn, inform steps to modify behaviour. O'Neill et al. (2017) conclude that using the tools to build team dynamics can improve student achievement levels and that a moderate to high level of usability and utility were reported by students; a key consideration when implementing any new software tools. This is echoed by LeNoble and Roberts (2021) who recommend the use of the tools due to the ease with which they can be distributed; the utility of the automated reports and; that the tools are currently free to use.

Based on the experience gained from the workshop, a brief literature review, and a subsequent reflection on how ITP Metrics could align with the teaching needs of the authors, the platform was chosen as the tool to be used in the pilot intervention detailed in this study. A summary of considerations is given below.

- The platform is free to use.
- The ease with which ITP Metrics could be deployed within existing activities and its flexibility to be deployed regardless of the discipline specific content of a given activity.
- The reflective nature of the assessments encourages students to gain; self awareness; an awareness of their teammates' traits and competencies and; an awareness of how to mitigate potential conflict caused by the differences in individual approaches and the interaction between different personal traits.
- The auto-generated reports contain detailed information on how to interpret the results and how different personal traits can deployed in different situations. Reports also contain exercises that aim to give students the opportunity to work on areas that they feel require improvement.
- The platform offers further support and resources to help instructors get the most out of the assessment process, including de-brief lectures and activities.

APPROCHES & RESULTS

Of particular interest to the authors are the two questions; *"Exactly where and when should each tool be deployed to ensure they are used at an appropriate time within a programme and by students with an appropriate level of experience?"* and; "*How do we properly structure learning exercises around the use of these tools to maximise learner benefit?"*

As detailed above, the tools are assumed to offer an overall benefit to supporting teamwork, but understanding how the tools deployment could be optimised would be of benefit. To begin to answer these questions, the School of Engineering piloted the use of ITP Metrics in the academic year 2022-23, using four of the platform's tools. The aim was to gather initial data to inform and develop future use of ITP Metrics. Prior to deployment off the tools, a mapping exercise was carried out to attempt to identify where each tool should be deployed. Figure 1 shows the outcome of this mapping exercise, with more a detailed rationale given in the sections below. After the students had used the tools they were invited to complete a survey consisting of a mix of Likert scale and open ended questions. The survey invitation was sent to 536 students and had a response rate of 12% (69 students).

ITP Metrics Tool: Team Contracts

The purpose of a team contract is to outline the standard operating practices and team norms for the team and individual members. Contracts were used with students in their first and second years of study; these students have the least experience with working in a team and so explicitly outlining teamwork expectations would be of most benefit. ITP Metrics provides a template contract and recommends an exercise to encourage students to develop their own contracts. However, given students lack of experience it was decided that they would receive a fully formed contract to read and sign. This contract was developed using ITP Metrics' template as a start point with changes made based on instructors experience of common issues and the input of a fourth year engineering student working as an educational development intern. Students were introduced to the contracts and given a rationale for their use during the first session of each module. They were then instructed to discuss the contracts as a team and decide on preferred modes of communication and preferred days and times for team meetings.

The contract exercises formed part of a timetabled, in-person sessions meaning engagement with the activity was high; all members from all groups signed a contract. Initial reactions to the activity were 50.7% 'Positive', 44.9% 'Neutral' and 4.3% 'Negative. All respondents either agreed or strongly agreed that the contract helped to set expectations, however when asked, on a scale of 1-10, how conscious they were of the presence of the contract after signing it, 59% of students rated their level of consciousness 5 or below. The survey data shows that all agree that a document detailing expectations is useful but in the current format it was rarely used and easily forgotten about; 85% of students reported that they or a team mate did not refer to the contract again during the course of the project. Anecdotal and casual conversations with the students after they had completed the contract exercise revealed several major themes:

- Although they acknowledged the need for clear expectations to be documented, they were aware of the fact that the contract was consciously artificial and therefore did not carry much weight in terms of helping team-members to remember their responsibilities.
- That the contract was unlikely to make much of a difference in terms of team-members' commitment to the team. In essence, it was felt that if a team member had decided to not participate already, then the contract was not likely to change their mind.
- That the prime motivator for completing the group tasks was the prospect of completing the programme itself and being awarded marks for the work.
- That the social contract that exists between team members was more powerful than the formal one – in some cases, students had immediately forgotten they had signed a formal contract.
- That the contract was perhaps unlikely to be used in any kind of conflict situation.

There was also an overarching sense across a large group of students that a contract was simply heavy handed and possibly unnecessary. A response in the survey likened using a contract to resolve conflict to "*telling your parent when someone hits you"* adding "*it's kind of cringe [embarrassing/awkward] and it's not the first thing people will resort to".* It appears that the contract would benefit from a change in format; instead of something formal that requires signatures it should be a document that lists individual expectations and team norms. A number of students noted in the survey that they would like to see *"more specifics on what each person should achieve".* A reminder of the document before each assignment may be useful along with a requirement that students amend it to clearly document how the workload will be allocated, perhaps a small percentage of the assignment grade could be given to this work allocation exercise. Five students mentioned that there should be "*punishment"* or "*consequences"* for not adhering to the contract. Although outside the scope of this study, it is interesting to note that perceived fairness of teamwork appears to be a factor in team conflict. If there is an expectation that instructors should be doing more to penalise poor performance, perhaps this should be considered when designing strategies to support students in teamwork activities.

ITP Metrics Tool: Personality Assessment

This assessment produces a report that outlines a participant's level on five factors of personality based on the responses to the completed questionnaire. The personalised report received upon completion describes how these personality traits can relate to team interactions and experiences in teamwork. The assessment was used with students in their first and second years of study as a strategy to help them gain experience with self-reflection exercises and to introduce them to the concept that understanding their own personality could help them better understand how they function within a team. The assessment was deployed in the fourth week of each module and was introduced and explained during a lecture with students instructed to complete it over the following week. During the lecture they were given some prompt questions to help them self-reflect on the outcomes along with some prompt questions to help them discuss and reflet the outcomes with teammates. This was an optional assessment with no credit value and no formal submission required.

Engagement for this activity was as follows: ENGG111 - 60.4%; AERO220 - 57.4% and; MECH212 - 63.5%. This is less that the contract activity, likely because students were instructed to complete the assessment in their own time. Initial reactions to the activity were 51.5% 'Positive', 45.6% 'Neutral' and 2.9% 'Negative. When asked if the personality assessment had helped them to reflect on their skills as a team worker, 56.9% of students said 'Yes', 26.2% said 'No', with 16.9% 'Not sure'. The open ended questions give a sense that whilst students found the assessment interesting, they did not make the link as to why it was relevant. Overall 13.2% found the assessment 'Very useful', 35.3% found it 'Somewhat useful', 35.3% were 'Neutral', and 16.2% found it a 'Waste of time'. Although some students found the results of the assessment interesting and two thirds of the class said that it had helped them to reflect on their own skills, it's not immediately clear if this assessment had any significant impact on improving group work skills: less than half of respondents found it useful. Students were instructed to discuss the results with team mates (if comfortable to do so) but this didn't happen and it is unclear at what level individuals carried out self reflection. 73.8% of students said that they did not discuss the results with team mates. When asked to choose (multi answer) any reason for not discussing, 48.9% chose 'I forgot to discuss the results', 42.6% choose 'I thought it would not help' and 17% said that they 'felt uncomfortable discussing the results'.

Of the students who did discuss with teammates, when asked to choose (multi answer) any outcome of discussing, 52.9% chose ‘it helped overall’, 29.4% chose ‘I understood more about teammates’, 17.6% chose ‘I worked to accommodate different personalities’ but 29.4% said that it ‘had no effect’. While the authors maintain that there could be some benefit to doing this activity, the current design of the activity did not work. It would appear that this activity requires more guidance and facilitation from instructors; to encourage students to reflect and discuss more thoroughly; and to more clearly place the activity in the relevant context.

ITP Metrics Tool: Conflict Management

This activity produces a report that can help to build awareness and create discussion about personal styles of conflict management. The associated questionnaire requires students to answer questions based how they would typically handle conflict in a professional setting. Used as a self-reflection exercise to improve team functions, students can gain greater awareness about scenarios in which each style would be the most effective. The assessment was used with students in their second, third and fourth years of study and who will have had some experience of teamwork activities. The assessment was deployed towards the end of the first semester of a module to ensure students would have had chance to experience teamwork and any related issues, giving them chance to provide more accurate answers to the questionnaire. The assessment was introduced and explained during a lecture with students asked to complete it anytime during the following week. During the lecture they were given some prompt questions to help them self-reflect on the outcomes along with some prompts questions to help them discuss and reflet the outcomes with teammates. Third and fourth year students were encouraged to complete a SMART action plan, based on their results, to help guide and track future progress. This was an optional assessment with no credit value and no formal submission required.

Engagement for this activity was as follows: AERO220 – 15.5%; MECH212 – 15.3%; AERO321 - 25.3%; AERO401 - 38.1%. Initial reactions to the activity were 37% ‘Positive’, 63% ‘Neutral’. Engagement and positive reactions to this activity are lower in comparison to the two earlier activities. This could be due to students feeling fatigue in completing these activities or because the personality assessment showed no immediate benefit; students may have assumed that this would be the case with this assessment too. One student reported “*[being] fortunate with my team so not had any conflicts to resolve”;* it could also be possible that the assessment was deployed too early i.e. no conflicts had occurred and therefore students didn’t see the need for activity at that time. When asked about their awareness of how they react in conflict situations, 23.1% of respondents reported ‘Full awareness’, 65.4% reported some awareness and 11.5% reported no awareness. When asked was the activity helpful in reflecting on how they dealt with professional conflict, 59.1% of respondents said ‘Yes’, 13.6% said ‘No’ and 27.3% weren’t sure. When asked if the report was useful or insightful, 81.8% said either ‘Yes’ (13.6%) or ‘Somewhat’ (68.2%). However, 80% of respondents reported that they did not feel the need to think back to the assessment after completing it and 87% of respondents reported that they did not discuss the assessment with teammates, with 60% citing that they ‘forgot about it’ and 35% that they ‘didn’t think it would be useful’. Whilst some of the survey data suggests that there is potential benefit, the current design of the activity did not fully engage students; they failed to discuss the results with teammates and in most cases just forgot about the assessment results. As with the findings from the personality assessment, it would appear that this activity requires more guidance and facilitation from instructors. One student suggested roleplay as way to facilitate discussion -*“Maybe create fake conflicts to encourage the groups to solve them using the techniques discussed”.*

It should also be noted that having students complete and discuss the assessment in their own time could be an issue; one student reported that *"If left to do [the activity] in our own time, and it isn't scheduled in the timetable, the likelihood for myself is that I just forget given I prioritise other tasks*" with another suggesting that "*[activities should be] timetabled in to make people do it rather than a 'spare time' thing."*

ITP Metrics Tool: Team Health Audit

This assessment allows students to assess the health of their team using the 'Team CARE' model, with the aim of ensuring a well functioning team. The associated questionnaire is completed by all members of a team with the results collated into a single team report. The report is generated to provide students with an idea of how they can direct their future actions toward improving teamwork. The assessment was used with Capstone students in their third and fourth years of study and who will have the most experience with team-based activities. These students, particularly the fourth year students, are usually well equipped to operate within a team but would still benefit form the fine tuning of team operations that this assessment can provide. The students were asked to discuss the results of the assessment and produce a SMART action plan identifying areas for improvement. The assessment was deployed at the end of semester one (both in year 3 and 4) with the discussion and action plan taking place at start of the semester 2, giving time for improvements to be made by the end of the year.

The engagement with this activity was as follows: MECH327 – 0%; MECH431 – 21 .3%; AERO321 – 0%; AERO420 – 11.9%.Initial reactions to the activity were 26.7% 'Positive' and 73.3% 'Neutral'. These results are much lower than the other activities and therefore no insight has been gained regarding this activity. Due to the small number of students who completed the activity and the subsequent smaller number of students completing the survey, no further results are presented here. However, some insight has been gained into the process by which these activities are deployed. These modules are project based and therefore rarely require students to attend lectures; it was difficult to organise a time to get all students together to introduce the activity and give a rationale for engaging. Instead, a short video was recorded and uploaded to the virtual learning environment with students then receiving email instructions to watch the video and complete the assessment. It is clear that this type of approach does not work and that all efforts should be made to gain student buy-in for these activities. It should also be noted that, whilst the rationale was sound for the timings of deploying this activity, in practice, it clashed with a busy assessment period for these students, offering another explanation for the poor engagement.

CONCLUSIONS

When this study was initial conceived, the intention was to pilot ITP Metrics in as many modules as possible, to gain as much data as possible. However, this approach has introduced limitations to the study. Many of the modules where ITP Metrics was deployed were not taught by the authors; whilst the module coordinators were accommodating and allowed the use of ITP Metrics in their modules, it was agreed that the authors would take all responsibility for deployment. This led to difficulties with the logistics of introducing, facilitating and monitoring the activities across all the modules and then reminding students to participate. This in turn has led to a lower engagement than expected, with some results based on a small proportion of the class. As the authors continue to develop the use of these tools, less modules will be included in the development phase, allowing more time to be spent on optimising the techniques required to deliver these activities.

It had been assumed that students would freely participate in these activities as their engagement would result in positive outcomes for them. This assumption was wrong. The results show a clear difference in engagement between the activity done in class and the activities done in students own time. This indicates that the biggest factor driving engagement is whether class time was allocated or not. It also indicates that students perhaps don't see a direct link between engagement with the activity and an improvement in their teamwork experiences. It would seem that students require more careful facilitation to discuss and reflect on their results to be able to understand how these tools can be of benefit. The information provided within the personised reports was assumed to be sufficient enough to allow for minimal intervention and facilitation from instructors but these results indicate this assumption to be wrong. The timing of the activities also appears to have impact on engagement; if they are deployed too early in a module students may not find them relevant and forget about them by the time they are required. It would also appear students would benefit form periodic reminders that the tools are available. The strategy by which the authors introduced these activities to students should also be noted; students were informed that the use of ITP Metrics was experimental and this perhaps may have discouraged some students from engaging. These initial results show that ITP Metrics can be a useful tool in developing student's teamwork skills however, work is required to properly integrate them into a programme. The authors will continue to use ITP Metrics, further developing and refining deployment approaches.

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BIOGRAPHICAL INFORMATION

Tony Topping is a Learning Technologist in the School of Engineering and a Master of Arts candidate in Academic Practice, both at the University of Liverpool. He has a technical background, having worked as Teaching and Research Technician for 15 years, where he developed and delivered authentic learning experiences. His current work focuses on blending pedagogic and technical knowledge; and the use of technology to enhance the teaching activities of the school.

Matt Murphy is a Senior Lecturer in Engineering Design and Director of Education at School of Engineering, University of Liverpool, UK. He is a metallurgist by background with a PhD and 10-year technical research career in the additive manufacture (3D printing) of metals. For the last 14 years Matt has worked primarily on learning & teaching and has held several leadership positions in the School of Engineering, with special responsibility for curricular and pedagogic reform. Matt teaches a range of courses in materials science & manufacturing, but most enjoys leading the group design project modules. He establishes and supervises a broad range of student projects in fields such as renewable energy, urban farming, sustainable transport; veterinary healthcare; circular economy; and the local recycling of thermoplastics. In recent years Matt has focused on developing authentic learning and assessment experiences that seek to replicate industrial practice within taught programmes.

Samuel Saunders is an Educational Developer in the Centre for Innovation in Education (CIE) at the University of Liverpool. He has worked in higher education since 2015, and has a background in academic, pedagogic and curriculum development. Sam is particularly interested in assessment and feedback, programme and learning design, research-led/research-informed teaching, and decolonising pedagogy/assessment. Sam also holds a PhD in nineteenth-century literature and culture, and has published widely in this area.

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ENHANCED ASSESSMENT AND LEARNING THROUGH ADAPTIVE COMPARATIVE JUDGEMENT

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ABSTRACT

The School of Engineering, University of Liverpool is trialling the use of Adaptive Comparative Judgement (ACJ) as tool to allow students to engage in a peer learning and assessment process. By examining three case studies, this paper describes how ACJ has been used in undergraduate engineering modules to enhance the assessment process for learning. The first case study in this paper describes how ACJ was used as an approach to provide feed-forward in a conceptual engineering design activity. It explores how ACJ has been used to facilitate a more structured approach to reviewing and contextualising examples of previously submitted work, in order to help students properly understand assignment expectations; and to provide some form of feed-forward. The second case study describes how ACJ is being used to facilitate peer assessment with the aim of increasing learner benefit. It was used to facilitate and inform peer discussion in an engineering ethics topic; and to help students reflect on their own attitudes and learning. The third explores how ACJ can be used to inform the final grade of a summative assessment and how the outcomes of completing an ACJ activity compare between students and teachers. The paper presents student perceptions and the authors experiences of using ACJ and discusses how such activities have been structured. Although the overall findings indicate that ACJ can be of benefit to teaching, more work is needed to optimise its deployment.

KEYWORDS

Formative Assessment, Peer Assessment, Peer Learning, Adaptive Comparative Judgement, Standard 11

INTRODUCTION

A key goal of a teacher is to foster an environment where students are able to engage in deep learning (Biggs & Tang 2011). In an effort to expand on current teaching strategies, The School of Engineering is exploring how to engage students in a peer learning and assessment process, the benefits of which are well documented (Topping 1998, 2009). Integrating a peer learning and assessment approach into an activity can support the development of skills such as collaboration and teamwork along with building confidence in the ability to communicate and externalise concepts to peers (Tanner et al. 2019).

Hansson et al. (2011) acknowledge that peer learning is often used to increase students' levels of deep learning, with their study concluding that it is an effective way to improve skills and that students participating in the activity feel more involved.
Although Hermon and McCartan (2011) note that there can be some issues with peer assessment, particularly with students inexperienced with the process, their study shows that helping students to develop self and peer assessment skills is worthwhile and that students report an increase in motivation just by participating in the process. A study by Jonsson et al. (2022) shows that students gain inspiration form viewing peer's work and find it useful to see how others solved the same problem, also noting that students found it useful to have input from someone other than just their supervisor. Peer assessment can also be a way to leverage the final piece of work and extend the learning of an activity after submission. As Bartholomew et al. (2022) points out, by not participating in the assessment of their work, students miss out on the benefits of applying higher order thinking skills such as critical evaluation and synthesis.

It is clear that a peer assessment and learning process can bring added benefit to an activity. But these strategies can be difficult to plan and implement with large cohorts and small teaching teams; strategies that employ deep learning often rely on small group teaching and intensive contact between students and teachers (Poot et al. 2020). This paper describes how The School of Engineering is implementing peer assessment and learning elements to a number of existing activities, using RM Compare as a tool to facilitate the process and to overcome some of the issues that come with managing larger cohorts.

PROPOSED INTERVENTION - RM COMPARE

RM Compare is an online digital tool that uses Adaptive Comparative Judgement (ACJ) to facilitate flexible approaches to both peer learning and peer assessment. ACJ is based on the work of Thurstone (1927) and later Pollitt (2004, 2012) who argue that making comparative holistic judgements, rather than using rubric based grading, can produce better results when evaluating the quality of work. To use the tool, work is uploaded to the platform before individuals are invited to participate in a judging session. Participants are presented with two pieces of work and asked to judge which they think best meets the assessment criteria; usually a single holistic statement. This pairwise comparison is repeated by different judges against different pieces of work over a number of rounds. As the judging rounds progress and a rank order of work begins to form, the tool will start to present participants with pieces of work that are closer in quality i.e., they have similar rank scores determined by judgements from previous rounds. This adaptive comparison can speed up the judging process and improve the overall reliability of the rank order (Pollitt 2012).

Whilst this tool can be used by instructors to quickly and reliably assess students work or as a tool to aid moderation and standardisation of grades, of particular interest to the authors is the tool's ability to facilitate deep learning through critical evaluation. By asking students to use RM Compare and participate in judging sessions, it is proposed that the tool can bring added benefit to existing activities; especially as the tool can be used regardless of cohort size.

Assignments that have open ended solutions can often be challenging for students as there is no single correct answer and it is not always clear what is expected of them to succeed. It is common practice to expose students to exemplar work from previous cohorts to help them better understand the task, but students might not properly engage; it can be difficult for students to internalise the criteria for quality just by viewing alone. Several studies have shown that using ACJ to facilitate feedforward or as a learning by evaluation tool can be beneficial; it

promotes student growth and learning and can increase student understanding of assessment criteria (Bartholomew et.al. 2022).
Kimbell (2018) notes that by evaluating peers work, students crystalise their own learning and improve their understanding of the difference between a good piece of work and the best piece of work. Bartholomew et al. (2019) add to this argument by reporting that students found it helpful to receive feedback from an ACJ process as it gave insights into where exactly improvement was needed. Seery and Canty (2017) describe how the exposure to peers' work can help a student position their own work relative to another's and that viewing the solutions formulated by peers to the same task gives insights to approaches and concepts that may not have been considered previously. Bartholomew et al. (2022) agrees that ACJ is an ideal way to provide an opportunity for students to be exposed to new ideas; a critical element in an engineering design activity and many CDIO themed activities.

Of particular interest to the authors, is a study by Canty (2012) that describes how during a design activity a student felt that they were "blinkered by one idea and missed out on a chance to be really creative" This is an attitude often encountered by the authors in their own engineering design activities but as Canty (2012) argues, the use of ACJ can be more critical than the task itself; the student can learn more by viewing their peer's concepts and approaches, even if they feel that their own design was lacking in comparison. Indeed, Bartholomew and Yoshikawa (2018) have suggested that ACJ is particularly suited to open ended problems and problem-based learning activities that are common in CDIO subjects, with Tanner et al. (2019) concluding that ACJ is compatible with the CDIO initiative and brings several benefits similar to the ones described above.

Much of the literature around ACJ, some of which is cited above and in particular a study by Kimbell (2022), report that it can be a reliable way to grade a piece of work. Given the time pressures that come with grading large volumes of work in large cohorts, the authors decided to use this pilot study to also explore how the rank order produced from students participating in an ACJ judging session could be used make their assessment more efficient.

APPROCHES & RESULTS

In order to investigate the possible benefits of using ACJ to enhance learning, the School of Engineering piloted its use in the academic year 2022-23 in two modules; '*ENGG111: Professional Engineering - A Skills Toolkit*', a first-year engineering skills module (n=220) and; '*MECH212: Engineering Design*', a second-year engineering design module (n=170). After the students had completed the activities in case studies 1 and 2, they were invited to complete a survey consisting of a mix of Likert scale and open ended questions. The survey invitation was sent to 390 students and had a response rate of 14% (54 students).

Case Study 1: Peer Review for Formative Learning

ENGG111 is a wide ranging first year engineering skills module where a new engineering ethics activity has been introduced (worth 1.5 credits). The first part of this activity introduces students to Equality, Diversity and Inclusion (EDI) topics; providing an awareness of the importance of EDI to the engineering profession and; as a foundation to activities in later years of study. ACJ was deployed here as a tool to allow students to participate in a peer assessment activity; the process not only requiring students to critically evaluate their peers work but also allowing them to be exposed to the views and experiences of the whole class, an important element to any EDI activity (Florian and Pratt 2015).Students worked in groups of six to create

an infographic that demonstrated their understanding of EDI topics; first carrying out some research into EDI and then holding group discussions on infographic content.
After students submitted their EDI posters, the judging session was introduced to students during a lecture; an overview of how ACJ works was given and; a rationale provided for the activity. Students were given a document instructing them on how to join the session and how to use the RM Compare interface. Each student viewed approximately 5 pairs of work, judging them against the holistic statement *“Which of these 2 posters best improves your understanding of EDI?”* Participation in the task was mandatory; a 50% penalty would be applied to the final grade of anyone who did not participate.

Engagement with this activity was high, 82% of the class participated, likely because of the grade penalty for non completion. When respondents to the survey were asked if they had a better understanding of the EDI topics after judging other groups posters, 15.2% ‘Strongly agreed’, 45.7% ‘Agreed’, 26.1% were ‘Neutral’, 10.9% ‘Disagreed’ and 2.2% ‘Strongly disagreed’. This indicates that there is some benefit to having students judge other groups work and the continued development and use of ACJ would be worthwhile. Whilst somewhat effective in helping learners improve their understanding of a topic more generally, it is clear that ACJ can help a student understand the quality of their own work; when asked if the activity had helped them to better understand the quality of their own work, 43.5% ‘Strongly agreed’, 45.7% ‘Agreed’, 8.7% were ‘Neutral’ and 2.2% ‘Disagreed’. When respondents were asked if viewing and judging other groups posters with RM Compare would be better than just viewing posters in an exhibition, 35.8% ‘Strongly agreed’, 34.8% ‘Agreed’, 23.9% were ‘Neutral’, 4.3% ‘Disagreed’ and 2.2% ‘Strongly disagreed’. This is an interesting result with implications on the design of other poster activities. The authors have experienced issues in the past with the logistics and cost of organising poster exhibitions, particularly with large cohorts. This result suggests that using RM Compare to facilitate an engaging poster exhibition may offer a solution to these issues.

Case Study 2: Feed-Forward in an Engineering Design Activity

MECH212 is a second year engineering design module where students work in groups of six to follow a formal design process from first brief; through problem definition, background research, and product design specification; to conceptual design; then fully embodied 3D CAD and manufacturing pack. ACJ was deployed here as a formative, feed-forward exercise to help students to properly understand the task; understanding what exactly makes a piece of work successful and; preventing them from taking the wrong approach to completing it. Mid-way through the module, students are tasked with producing a concept design poster that demonstrates their design thinking; showing details of how they arrived at a final concept via initial concepts, concept selection and concept development. At the start of the poster assignment process, students were invited to judge and compare all the posters from the previous year’s assignment. The judging session was introduced to students during a lecture; an overview of how ACJ works was given and; a rationale provided for why they should participate i.e. *by participating you will be more likely to produce a better poster and score a higher grade for the task.* Students were given a document instructing them on how to join the session and how to use the RM Compare interface. Each student viewed approximately 10 pairs of work, judging them against the holistic statement *“Which of these 2 posters best describes the evolution of the Concept Design?”* Participation in the task was not linked to the final grade and no extra credit was awarded for completion.

Engagement with this activity was much lower than the activity in case study 1, only 26% of the class participated. This is likely due to there being no grade penalties for non completion in this activity.

When respondents from to the survey were asked if they had a better understanding of the poster assignment after judging last year's posters, 25% 'Strongly agreed', 50% 'Agreed' and 25% 'Disagreed'. This indicates that students do gain benefit from using ACJ to facilitate a feed-forward activity. Figure 1 shows how the final group grades differed depending on whether group members completed the feed-forward activity. These results show that by completing the feed-forward activity, a groups work will be of higher quality. However, it is noted that at least half of the group must have completed the activity to gain this benefit. This is likely because, in the authors experience, student approaches to group work tends to be siloed; they complete their own sections of work before compiling it at the last minute. Another interpretation of these results is that the type of student who is likely to produce a good piece of work is more likely to complete this type of activity, hence the correlation between ACJ completion and high grade. When asked if the activity had helped them to better understand the quality of their own work, 62.5% 'Strongly agreed', 12.5% 'Agreed', 12.5% 'Disagreed' and 12.5% 'Strongly disagreed'. This follows on from the findings in case study 1 that ACJ is beneficial to student understanding of the overall quality of their work.

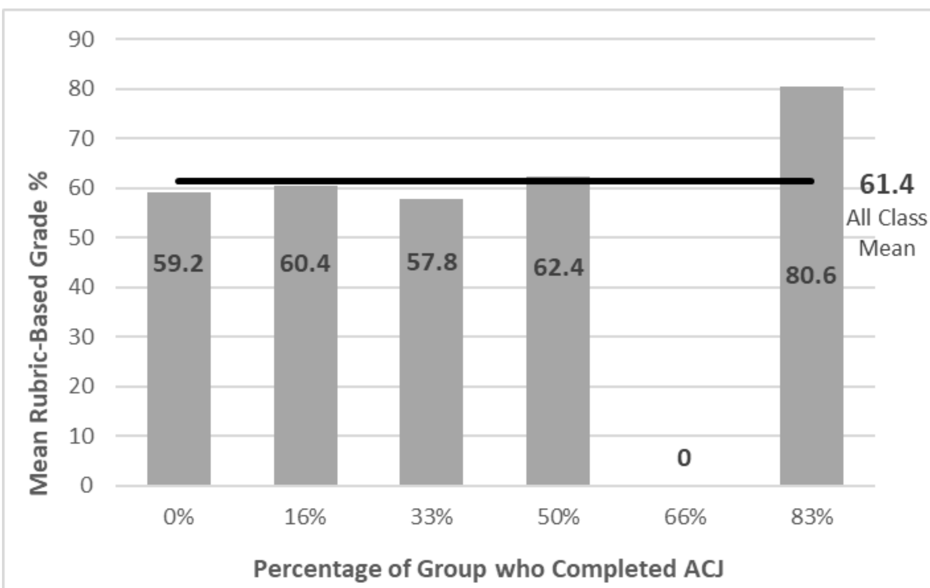

Figure 1. The relationship between the percentage of group members that completed the ACJ activity and that group's mean grade.

Case Study 3: Summative Peer Assessment

As a first step in exploring the relationship between rubric-based grades and grades based on ACJ ranking, a direct comparison was made between the instructor rubric-based grades given to concept design posters from last years cohort and the ACJ rank orders for the same posters produced by this years cohort during the feed-forward activity. The teaching team (n=5) that graded last years posters using a rubric were also asked to grade the same posters again using ACJ. In order to make a direct comparison between ACJ rank order and the rubric-based grade, a rank order of the rubric-based grades was produced. The grade for each poster was then placed in descending numerical order. This rank order of grades was then transposed directly to the ACJ rank order; essentially, awarding the top ACJ ranked poster the same grade as the top ranked rubric-based graded poster and so on.

Figure 2 shows the rubric-based grade of last years posters in comparison to the ACJ ranks produced by the same teachers who graded the posters and the rank produced by students who completed the feed-forward exercise. There is broad correlation between ACJ rank orders and rubric-based grades. The correlation between teacher rubric-based grade and teacher ACJ ranking shows that ACJ may be a reliable alternative method for teachers to grade work. Depending on the type of assignment and the number of pieces of work being graded, ACJ has the potential to reduce the amount of time taken to grade an assignment. For example, grading all the posters took around 3 hours using a rubric but took each judge around 30 minutes to complete the ACJ exercise. The correlation between student ACJ ranking and teacher ACJ ranking offers evidence that student rankings can be reliable; given that some students seemed distrustful of student rankings, this is an important finding and will be used to build trust in future activities. When respondents to the survey were asked if they would be comfortable with RM Compare being used to help inform the final grades in future assignments, 20.4% ‘Strongly agreed’, 31.5% ‘Agreed’, 31.5% were ‘Neutral’, 7.4% ‘Disagreed’ and 9.3% ‘Strongly disagreed’. When asked if they trusted their classmates to use RM Compare properly, 13% ‘Strongly agreed’, 25.9% ‘Agreed’, 29.6% were ‘Neutral’, 22.2% ‘Disagreed’ and 9.3% ‘Strongly disagreed’. Some of the larger differences between teacher grade and ACJ rank order were examined; it appears that when using a rubric-based grade system, students were graded more harshly i.e. whilst some posters were good overall, students lost points because they had misunderstood the exact criteria requirements for a single section of the task. Given that the purpose of the assignment is to allow students to demonstrate their *whole* design story, the holistic approach to grading used in ACJ may be more appropriate.

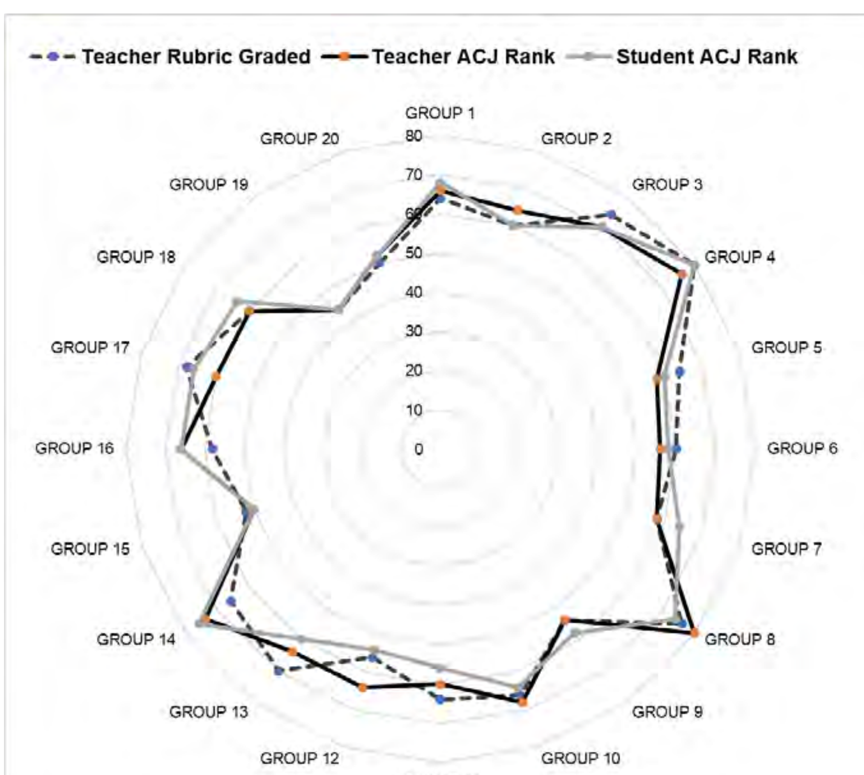

Figure 2. The relationship between final teacher rubric-based grade and the comparable grades created with the ACJ rank order produced by teachers and students.

Further Investigation: Using ACJ To Enhance Instructor Rubric-Based Assessment

After noting the correlation between grading shown above, the authors wanted to further explore how ACJ could be used in the grading process, asking the question "*Would it be possible to reduce the amount of time instructors spend grading student work by only asking instructors to grade a sample of work, and then using the output of a student ACJ session to generate grades for the whole class,?"* To investigate this, the instructor rubric-based grades given to concept design posters produced by last years cohort was taken as the starting point. This data is plotted in figure 3 as 'Rubric Grade'. Next, an ACJ informed grade was created, plotted in figure 3 as 'ACJ Grade'. To create the ACJ informed grade a plot was first created that described the relative position of each piece of work. This plot was created using the "Parameter Value", an output of the ACJ calculations assigned to each piece of work and used to determine the rank order. The top, middle and bottom rubric-based grades where then used to calibrate the upper, middle and lower limits of the new grade before extrapolating the grades between these limits using the Parameter Value curve. Figure 3 compares the spread between these two different grades showing good correlation between the two. It could have been possible to apply the grades in a linear fashion, as was done in the Summative Peer Assessment study above, but this would not have allowed for the relative differences in quality between adjacently ranked work to be demonstrated. The Parameter Value produced by ACJ does account for this, so would seem sensible to make use of it to produce a more realistic grade distribution.

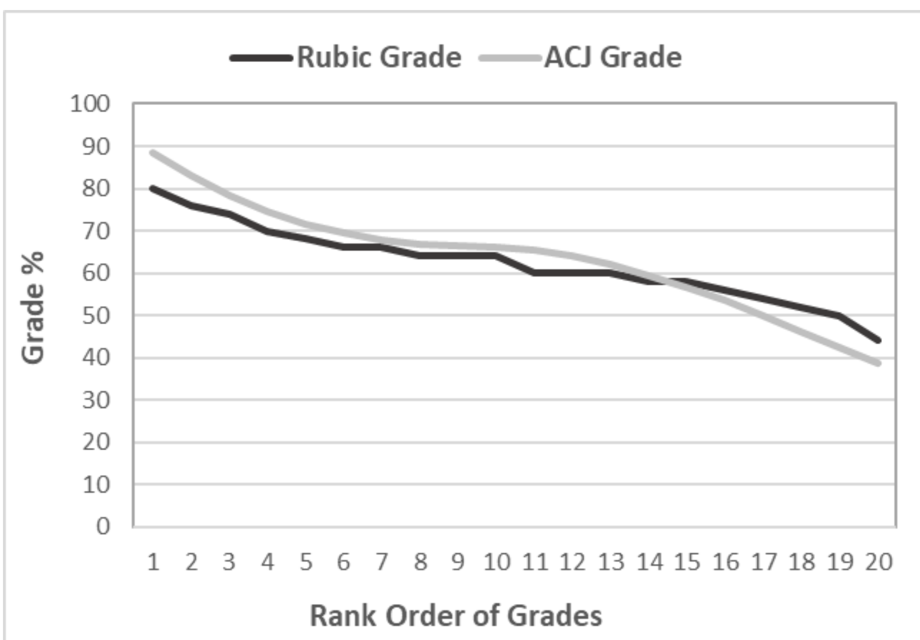

Figure 3. A comparison of the spread of grades using rubric-based grading vs using ACJ informed grading.

Figure 4 then compares the actual rubric-based grades to the grade a group would have received if the ACJ informed grades where used. Whilst it is interesting for this study to directly compare ACJ informed grades to rubric-based grades, it should be noted that the two methods for producing grades are different and therefore a difference in grades is to be expected. However, the fact that there is broad correlation between the grades produced by dissimilar grading methodologies is interesting and indicates a promising area of further work.

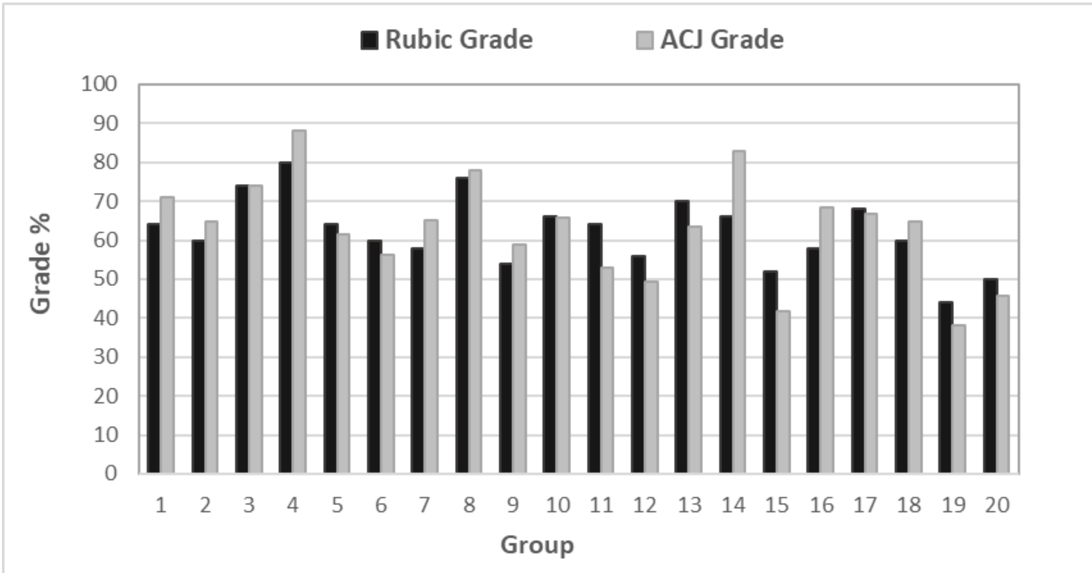

Figure 4. A comparison of actual rubric-based grade vs the hypothetical ACJ informed grade.

CONCLUSIONS

All respondents to the survey either ‘Strongly agreed’ (65.2%) or ‘Agreed’ (34.8%) that the RM Compare platform was easy to use and when asked if they would like to see RM Compare used in other activities, 25.9% ‘Strongly agreed’, 38.9% ‘Agreed’, 31.5% were ‘Neutral’, 1.9% ‘Disagreed’ and 1.9% ‘Strongly disagreed’. These usability results, when taken with the results showing that ACJ can bring additional learner benefits, indicate that there would be value in continuing to develop and deploy ACJ activities. The results around using ACJ to grade work are also promising; as class sizes get bigger and staff time becomes more precious, anything that has the potential to save time would be welcomed. Importantly, ACJ is scalable; it can be used in a class of 50 or 500. This scalability is not only useful when thinking about grading for large cohorts but also when designing activities for large cohorts. There is evidence to show that students have benefited somewhat from the deep learning that comes with critical thought, all without major facilitation from instructors. Add to this the finding that students are receptive to the idea that ACJ could replicate a poster exhibition, all be it asynchronously and at a fraction of the cost, suggest a number of promising directions for further work. The authors will continue to use ACJ; the results from this initial study informing how they will develop strategies to make further use of ACJ and; forming the basis of a new study into the possibility of using ACJ to assist with grading.

Student feedback and the authors experience of deploying ACJ have highlighted a number of areas of further work that would improve future activities. The different levels of student engagement between the activities indicate that how the activities are deployed is an important factor in how effective they are. It had been assumed that students in second year of study would be mature enough to be left to complete the activity in their own time and that being told the activity would likely increase their grade would be incentive enough to do so. This assumption was wrong. The authors strongly suggest allocating class time to complete these activities as a strategy to improve engagement, beyond linking completion to final grade; from past experience this is the best way to get students to complete not-for-credit activities such as module evaluation surveys.

The strategy by which the authors introduced these activities to students should also be noted; students were informed that the use of ACJ and the RM Compare software was experimental and this perhaps may have discouraged some students from engaging. Some students completing the activity in case study 1 reported that some posters were taking too long to read and so weren't fully engaging with the judgements. The authors ran a number of ACJ pilot sessions with other staff and found that if the holistic statement (judging criteria) or the pieces of work being judged were too complex, judgments would default to being made based on the aesthetics of a piece of work. These findings indicates that thorough consideration should be given to both the work being judged and the criteria for judging, as well as the number of judgments students are asked to make. Some students in case study 1 reported that some of their classmates weren't engaging with the session properly because they had realised that they could quickly complete the activity by randomly selecting a piece of work without properly engaging in a judgement. It is possible to have the RM Compare software require students to leave rationale for their judgments which may overcome this issue.

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BIOGRAPHICAL INFORMATION

Tony Topping is a Learning Technologist in the School of Engineering and a Master of Arts candidate in Academic Practice, both at the University of Liverpool. He has a technical background, having worked as Teaching and Research Technician for 15 years, where he developed and delivered authentic learning experiences. His current work focuses on blending pedagogic and technical knowledge; and the use of technology to enhance the teaching activities of the school.

Matt Murphy is a Senior Lecturer in Engineering Design and Director of Education at School of Engineering, University of Liverpool, UK. He is a metallurgist by background with a PhD and 10-year technical research career in the additive manufacture (3D printing) of metals. For the last 14 years Matt has worked primarily on learning & teaching and has held several leadership positions in the School of Engineering, with special responsibility for curricular and pedagogic reform. Matt teaches a range of courses in materials science & manufacturing, but most enjoys leading the group design project modules. He establishes and supervises a broad range of student projects in fields such as renewable energy, urban farming, sustainable transport; veterinary healthcare; circular economy; and the local recycling of thermoplastics. In recent years Matt has focused on developing authentic learning and assessment experiences that seek to replicate industrial practice within taught programmes.

Samuel Saunders is an Educational Developer in the Centre for Innovation in Education (CIE) at the University of Liverpool. He has worked in higher education since 2015, and has a background in academic, pedagogic and curriculum development. Sam is particularly interested in assessment and feedback, programme and learning design, research-led/research-informed teaching, and decolonising pedagogy/assessment. Sam also holds a PhD in nineteenth-century literature and culture, and has published widely in this area.

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AN INTRODUCTORY REVERSE ENGINEERING PROJECT TO ENHANCE TEACHING STAFF AND STUDENT COMPETENCE

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ABSTRACT

This paper details the development and evolution of a reverse engineering project undertaken by all first-year engineering students at Nottingham Trent University (NTU). The paper elaborates on how the teaching and assessment methods used in the project can be utilised to enhance student as well as teaching staff competence. It is argued that technical staff play a vital role in supporting and delivering project-based learning and are likely to receive more student feedback outside of formal student surveys. Consequently, increased technician involvement in the development of the project is utilised in the hopes of better capturing student learning needs and ensuring students are given a good first introduction to using hand and measurement tools. Simultaneously, delivering such a project requires the staff to learn new tools and acquire relevant skills, thereby enhancing faculty competence. Instead of using multiple, smaller and discipline specific devices reported previously, a single and larger device is reverse engineered across all disciplines for the project at hand. Reverse engineering the same device across disciplines is proposed as a means to move away from engineering silos by unifying the tools used and the skills gained during the project. Furthermore, student feedback and technician perspectives are presented to paint a holistic picture of the delivery of the project from the standpoint of students, technicians and the academic. Finally, recommendations are put forth on how to further improve the delivery of such a project and increase technical staff involvement in an engineering curriculum.

KEYWORDS

Introduction to engineering, reverse engineering, engineering design, CAD, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 11

INTRODUCTION

Nottingham Trent University (NTU) established a new engineering department in 2017 with a modern approach to delivering engineering education. The approach acknowledges that it is essential to develop the general skills of future engineers along with specialised skills (Suzuki et al., 2022). The delivery of this curriculum is built upon 4 pillars:

1. **Tools:** Graduate engineers have suitable toolkit to tackle engineering challenges
2. **Skills:** Graduate engineers have necessary skills to effectively use engineering tools
3. **Creativity:** Graduate engineers have the desire to put forth creative ideas on which they use their skills
4. **Delivery:** Graduate engineers have had experience of taking their creative ideas from concept to production in a timely and organised manner

Engineers in the industry can often find themselves working with unchartered, open-ended, and complex problems (Jonassen et al., 2006; Zhu et al., 2019). Therefore, the engineering curriculum at NTU focuses on experiential learning – allowing students to work on several projects, to give them an experience of what real world engineering challenges might look like. This is the opposite of traditional, didactic learning (Gadola & Chindamo, 2019) and instructors involved in delivering this type of learning aim to facilitate student learning as opposed to acting as mere transmitters of information. There is an abundance of literature to support the efficacy of project-based learning in improving students' collaboration skills, communication, academic achievement and learning motivation (Chen & Yang, 2019; Hmelo-Silver, 2004; Ralph, 2016; Yadav et al., 2011).

It has been argued that the students' wellbeing and social competencies within a team takes precedence over academic achievement in the delivery of quality project work (Flarup & Wivel, 2018). Indeed, graduates with market-oriented skills, such as managing projects, comprehension of engineering economics, teamworking skills, and (or) competence using engineering tools are more desirable for employers (Yang, 2019). In the pursuit of producing high quality and employable graduate engineers, budding engineers need to be put in learning environments that allow them to learn a multitude of skills simultaneously. Previous research has shown that such a learning environment is achievable through the implementation of CDIO standards (Butt & Siegkas, 2021; Deweck et al., 2005; Mazini et al., 2018; Siegkas, 2020; Yang, 2019)

A recurring issue in engineering education is the reinforcement of disciplinary silos (Fitzpatrick et al., 2021; Hoople et al., 2018). The ever-changing landscape of modern technologies in the fourth industrial revolution has brought interdisciplinarity front and centre (Roy & Roy, 2021) and highlights the importance of producing engineers with diverse expertise rather than being discipline specific experts. Moreover, it is obvious that contemporary and future grand challenges are not limited to specific disciplines and require an interdisciplinary approach to create innovative solutions.

In creating a conducive learning environment, it is important for the instructors to make learning easier for the learners and to work with them towards knowledge construction (Mohedo & Bújez, 2014). From personal experience, to become change agents, instructors must be aware of the learning outcomes and have significant involvement in planning project-based activities. Several project-based modules at NTU employ the services of technicians, for setting up workspaces/ laboratories as well as demonstrations. In essence, the technicians play a role in the delivery of these projects as instructors. This paper builds upon the work previously presented (Butt & Siegkas, 2021; Siegkas, 2020) and explores CDIO implementation in a first-year engineering project with a focus on involving engineering technicians in the planning and delivery of the project. This early involvement is strategic, in that the technicians are allowed to disseminate their technical knowledge to engineering students early on in their student journey and in doing so, the competency of the entire technical team is improved. An effort is made within the project to minimise the reinforcement of disciplinary silos, both within the student body and the technical team.

PROJECT DESCRIPTION

The reverse engineering project presented here is part of a core module (Innovation and Engineering Solutions) undertaken by all year 1 engineering students at Nottingham Trent University. The courses enrolled in the module are Mechanical, Sport, Biomedical and Electrical & Electronics Engineering. The module runs throughout the academic year and has 4 items of assessment, each contributing 25% to the module. The reverse engineering project is the first of many projects undertaken by engineering students at NTU; readers interested in previous iterations of this project are redirected to (Butt & Siegkas, 2021) and (Siegkas, 2020).

The project learning outcomes included:

- Recall engineering principles related to the properties of materials and engineering components to describe their interaction with the environment and end user.
- Describe characteristics of materials, components and devices and their applications
- Recognise the limitations in an engineering system by considering a product's materials, design, and assembly.
- Competently and safely use machinery, hardware and software in the design, assembly/disassembly, and production of components and/or products.
- Work as a member of a team to undertake a small engineering project and deliver its results in a format suitable for a relevant industrial audience or stakeholder.

Project delivery: There were 255 students enrolled in the module. Groups consisting of an average of 9 members were created, giving a total of 28 groups. The aim of the group project was to introduce first year students to reverse engineering by deconstructing an engineered device into its constituents, documenting these in a bill of materials and then examining these in detail by discussing the function of each constituent element and proposing how this can be improved before finally reconstructing the device. The groups had to design the deconstructed parts using Computer Aided Design (CAD) on Autodesk Fusion 360 (Autodesk, 2022) and then create a virtual assembly of these components. The reverse engineering workshops were structured as Gateways which were used as opportunities to provide feedback (CDIO Standards 1, 2, 3, 4, 5, 7, 8)

To enhance the CAD modelling skills of the students undertaking the project, CAD tutorials were run in tandem with the project. The project took place over 10 weeks, where 5 weeks were dedicated to workshop sessions where the engine was reverse engineered while the other 5 weeks were dedicated to CAD sessions. An outline of these sessions has been presented in Table 1. The sessions were run in an alternating manner, whereby students would attend one CAD session and attend the reverse engineering workshops in the following week.

Table 1: Outline of the reverse engineering project sessions

Reverse Engineering Project	
Session	**Content**
Workshop 1	Gateway 1: Preliminary analysis and Deconstruction
Workshop 2	Gateway 2: Deconstruction, Measurements and Documentation
Workshop 3	Gateway 3: Bill of materials
Workshop 4	Gateway 4: Functional analysis and proposed improvements
Workshop 5	Gateway 5: Reconstruction
CAD session 1	Introduction to CAD, Sketching, Extrudes
CAD session 2	Patterns, Revolves and Fillets
CAD session 3	Sweep and Loft (with guided lofts)
CAD session 4	Assembly and Animations
CAD session 5	Drawings and BoM

Separate workspaces were provided to students to work on the project. For modelling, students used the purpose-built design and simulation suite with high spec desktop computers where they could use the CAD software to learn and model their parts while the reverse engineering took place in the engineering design suite where hand/measurement tools were provided along with the engine and manual/guides (CDIO Standard 6). The engineering design suite is an open plan room with ample space for students to work in groups and has limited computers and a separate provision of laptops should they require these for documentation/ modelling. In the last three years, the reverse engineering project has evolved from using household appliances to discipline specific appliances and now finally standardising the reverse engineered device to an engine. The engine used for the project is provided in Figure 1.

Figure 1: Honda GP 160 Engine used for the reverse engineering project (Image courtesy of Honda)

Engine selection: The technical team were tasked to procure a suitable engine for a project of this scale. There were some challenges in the selection of the engine; some engines available on the market had very few parts and as such lacked the complexity needed to target the expected learning outcomes. It was crucial to ensure enough parts were available for all students to take part in the deconstruction, measure the parts, design them using CAD, create a bill of materials before finally conducting a functional analysis to suggest improvements. One of the engines that was explored was a small 49cc quadbike engine made by iMars (ebay, 2022) - the engine retails at £50. This engine was relatively cheap and had ample number of parts that were suitable for this project. However, the lack of standard part sizes for this engine meant finding the tools to deconstruct this engine would prove tricky. In essence, a significant number of tools would have to be procured to deconstruct this engine. After much deliberation, the technical team concluded that the budget had to be increased to procure a high-quality engine that was of an appropriate size, had ample parts and had standard sized parts. After exploring various options, Honda GP160 (Honda, 2022) was agreed upon as the most suitable option. These engines had the right number of parts, were small enough to transport easily and had metric sizing with every nut and bolt being an M6 x 10/12mm. The standard metric sizing meant that the tools were much easier to buy and in the event of loss/damage, spare parts were readily available. Only one engine was ordered initially for testing and once the technical team were satisfied with the engine build and ease of deconstruction, a further 29 engines were ordered for a total of £6,061.

Engine preparation: Upon delivery it was found that each engine had 25ml of oil to prevent the parts from seizing or sticking to each other under varying temperatures during delivery. The oil was first drained from the engine after which they were disassembled. The entire technical team (10 technicians) and the module leader were involved in the deconstruction of the engines to ensure everyone involved had an appreciation of the constituent parts of the engine as well as gain insights into how the engine functioned. Although 2 – 4 technicians were committed in the delivery of the project, all technicians had to undertake the deconstruction in case a cover was required in the absence of the primary technicians involved. Upon deconstruction, the engines were cleaned with WD40 and then put back together. It is noteworthy that the technicians involved in the deconstruction/ reconstruction had varying technical specialities; some had Biomedical Engineering technical expertise while some came from an Electronics background. Technicians were encouraged to learn how to use hand tools during this exercise to improve their competence and ensure they had ample knowledge to teach students the use of specific tools such as strap wrenches and bearing pullers.

Manuals and guides: A deconstruction manual was prepared while the technical team deconstructed the engines. Notes and pictures were taken at various stages of the deconstruction and a brief description along with some labels were later added to each picture to create a step-by-step guide. Once a first draft of the guide was created, another technician followed this deconstruction manual to deconstruct another engine. This exercise allowed receiving feedback on the first draft to ensure appropriate revisions were made. This process was repeated several times to perfect the deconstruction manual. The order of the document was also changed a few times to ensure the most optimum deconstruction methods were articulated in the deconstruction manual. The instructions had to be clear and easy to understand; they were created with the assumption that the students following this guide may have never seen an engine before. A similar approach was adopted in creating a reconstruction manual. It is noteworthy that the reconstruction steps were not simply the deconstruction backwards as some parts needed to be put back first before the other parts to allow easier access. In addition to the deconstruction and reconstruction manual, a Reverse Engineering Laboratory Manual was also prepared that the students could use to aid them in collectively document the reverse engineering project progress. This manual was split into 5 sections, each section corresponding to the gateways described earlier.

Figure 2: (Left) An extract from the deconstruction manual (Right) An extract from the measurement guide.

A measurement guide was also prepared and made available for the students to instruct them on the correct usage of specialist measurement tools. The measurement tools covered in the guide included a micrometre, spring loaded bore gauge and feeler gauges. Excerpts from the deconstruction manual and the Measurement Guide can be seen in Figure 2

Project gateways: Students were expected to fill in the reverse engineering laboratory manual on a bi-weekly basis. Each gateway of the manual focused on a specific task. At the start of the session, students were briefed on the task at hand and provided some pointers on best practices for successful completion of the task. Throughout the reverse engineering sessions, the module leader and a few members of the technical team were always present to supervise the students and facilitate them. Facilitation took the form of suggestions, demonstrations on how to use measurement/hand tools, assistance in designing components, and formative feedback at the end of the session. The module leader and technicians would also spend some time with each group every session as a form of mentoring/coaching to check in on their team dynamics and suggest ways to mitigate any issues and (or) lack of engagement.
The description of each gateway and the respective task is provided as follows:

Gateway 1: Deconstruction and Preliminary Analysis - Students were expected to provide a preliminary analysis while deconstructing the engine. Safety briefing and tools required to deconstruct the engine were provided to the students. The preliminary analysis was provided by the groups based on a set of probes provided in the laboratory manual, such as *what is the device? How does the user interact with the device? Why is the device designed in this way? How does the device work? How would you improve this device?*

Gateway 2 - Deconstruction, Measurements and Photographed Documentation: Students were expected to document the deconstruction of the device by itemising the engine and photographing the constituent components. Students were expected to place each deconstructed component in a labelled bag. The students were reminded that they had to produce CAD models of the constituent components and were encouraged to measure the components. Various measuring tools were provided to achieve this, and the students were encouraged to document the measurements in the laboratory manual.
Gateway 3: Bill of materials - Students were expected to document the deconstruction of the device by identifying the materials, function, interaction, price, etc. of the constituent components. A generic bill of materials was provided to the students to populate in the laboratory manual.
Gateway 4: Functional analysis and proposed improvements - Students were expected to conduct a thorough functional analysis of each component of the device and propose any improvements. Students were provided spaces in the laboratory manual to include two paragraphs; the first paragraph detailing what the part is (function and interaction), the material used to make it and how it has been manufactured and the second paragraph to suggest ways to improve the component.
Gateway 5: Reconstruction - Students were expected to reassemble the entire engine and provide an image of the reconstructed engine in the laboratory manual. Students were encouraged to note down steps taken in reassembling the engine, the tools used, and any challenges faced while reassembling

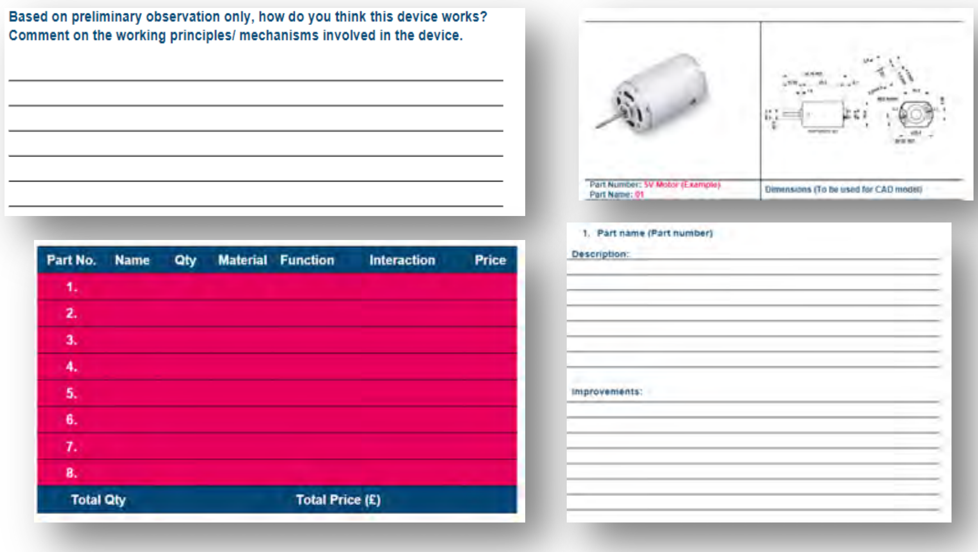

Figure 3: Some excerpts from various sections of the reverse engineering laboratory manual.

Project outcome: At the end of the project, students were required to submit a group report that detailed the following (CDIO Standard 11):

1. Background of the engine
2. Methods adopted and tools used
3. Bill of materials
4. Functional analysis of the engine components
5. Suggested improvements to the engine components
6. CAD models of the engine components and their assembly

Students were required to model at least 14 components using CAD. These components included air filter, fuel tank, exhaust, fan casing, recoil starter assembly, crankcase, crankcase cover, piston assembly, crank shaft, cylinder head and valves, camshaft, carburettor, fan, and flywheel. For details on the marking scheme, interested readers are redirected to (Butt & Siegkas, 2021)

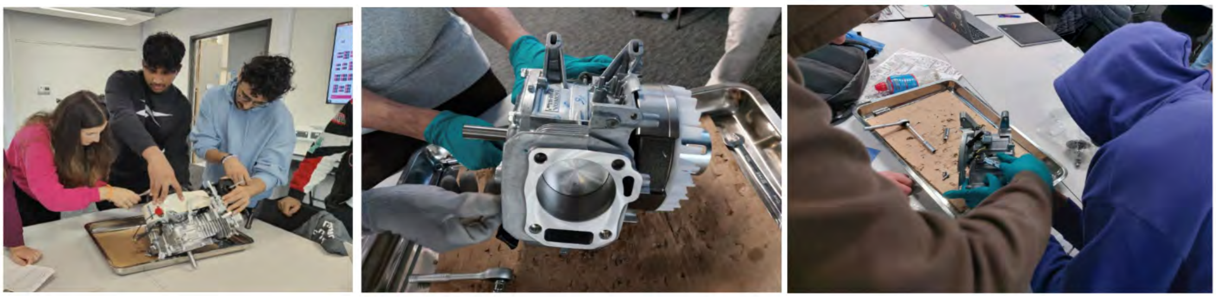

Figure 4: A few examples of the students at work in the laboratory sessions (Images courtesy of Group 16)

DISCUSSION

Module leader perspectives: The type of device used in the latest iteration of the reverse engineering project was selected for a few reasons. Standardising the device meant project management from an academic's point of view was easier. In each reverse engineering laboratory session, there was a quick CAD demonstration to contextualise modelling in terms of the engine being deconstructed. As an example, by the end of laboratory session 1, students had already learnt extruding in CAD in the week prior to this session. The demonstration focused on using extrude to create a component of the engine – the air filter in this example. Having run reverse engineering sessions with multiple devices in the previous iteration, it was hard to provide a similar demonstration as the devices were different for various groups. Standardising the device also meant that all students from various background worked on the same device following similar procedures using the same manuals and guides. Although engines are traditionally associated with Mechanical engineers; Electronic, Biomedical and Sport engineering students had an opportunity to work with a device that is traditionally not associated with their discipline. The aim was to give the students something to work with, without consideration for the relevance to their discipline, rather encouraging them work outside their comfort zone and focus on creativity, design skills, team working and project management. Standard devices also meant standard measurement and hand tools which worked well when considering resource management. All technicians, irrespective of their disciplinary backgrounds, deconstructed the same engine, ensuring they revisited their hand/ measurement tool skills if they were familiar with the tools already. If they had not used these tools before, this exercise encouraged them to learn tools and, in the process, enhance their competence (CDIO Standard 9).

Some reservations from Electronic, Sport and Biomedical engineering students on the type of device was expected based on prior experience. However, majority of the students engaged well with the device and found the sessions interesting, motivating them to learn more. In fact, the authors learnt quite a few new things such as the use of hand tools and the assembly of the engines used. As an example, author 1 learnt how to use a bearing puller, piston spring compressor and a strap wrench while author 2 picked up new CAD skills such as using 3D sketching and sweep to create gear teeth. The student outputs were impressive, in that the CAD modelling skills improved immensely over the course of the project than previous iterations of the project. This improvement is partly attributed to the complexity of the device used compared to previous iterations, but it is evident that the CAD demonstration in the laboratory sessions helped in making CAD modelling features such as extrudes and revolves more relatable. Some examples of the students recorded measurements and part modelling skills are shown in Figure 5, Figure 6.

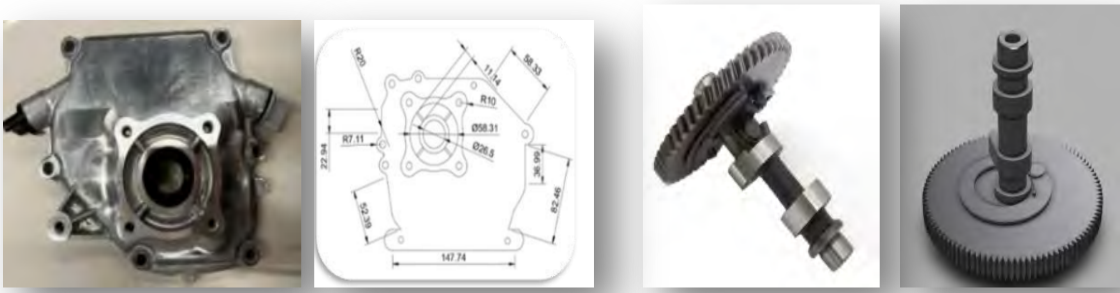

Figure 5: (Left) Measurements recorded in the laboratory manual (Right) CAD model of the engine camshaft (Images courtesy of Groups 20 & 26)

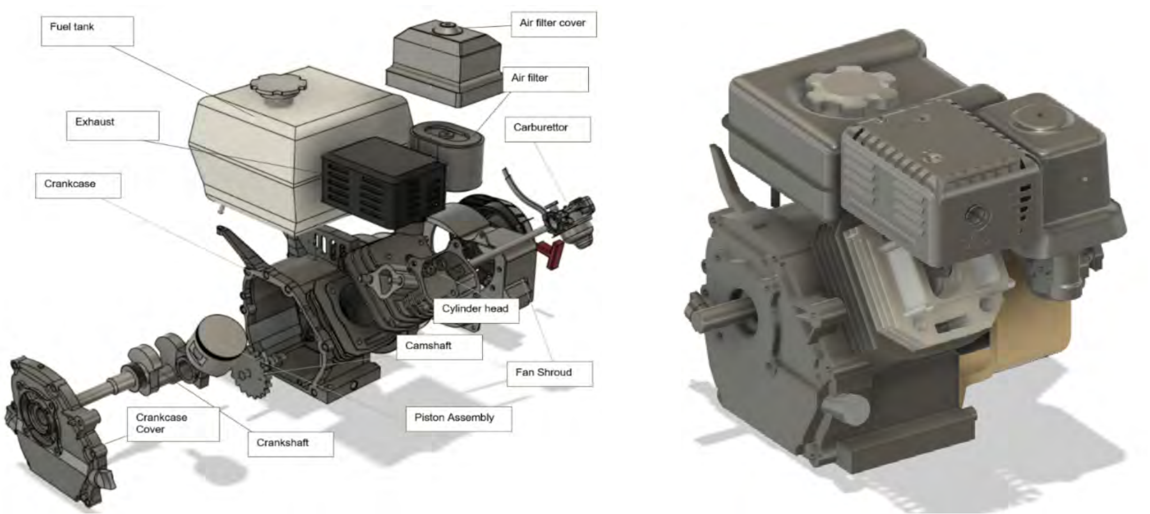

Figure 6: Examples of the CAD assemblies of the engine created by student groups (Images courtesy of Groups 7 & 9)

For the bill of materials, students were encouraged to focus on materials, manufacturing, and the pricing. Students were asked to justify how they arrived at the prices for each component. The prices were calculated in two ways: weighing the components, deducing its material based on research and the looking up standard material prices per unit mass from vendor websites or by simply looking up spare parts available online and then calculating the cost price of the part by subtracting an estimated profit margin from the selling price. An extract from a student group created bill of materials is presented in Figure 7.

Part no	Name	Quantity	Material	Function	Interaction	Price
1.	Air filter	1	Aluminum and Foam	Prevents or traps and holds any dust particle or debris from reaching the engine for better performance	Interacts with throttle valve Assembly	5.40 lsengineers.co.uk

Figure 7: Extract from a BoM created by a student group (Image courtesy of Group 20)

For the functional analysis and proposition of improvements, students were encouraged to research each part, its function, material, manufacturing methods as well as any alternatives that could be used for a specific part before proposing improvements. Students were reminded that when proposing improvements, they would need to discuss how the suggested improvements might have an impact on the components' prices, user-friendliness, and environmental impact (CDIO Optional Standard 1). In essence, students were asked to consider the Triple bottom line, catering to the social, economic, and environmental impact (or 3Ps – people, planet, and profit) and in doing so make trade-offs to conclude which suggested improvements from all the parts would they take on board in improving the entire engine. The aim was to improve the student's attention to detail while also ensuring they considered the broader context by considering modularity, ease of maintenance and use. Students made some fascinating suggestions, and most groups considered the bigger picture. As an example, a student group suggested improving the air filter casing by first deducing that air filters are injection moulded polypropylene and as such one improvement could be 3D printing these parts to avoid creating expensive moulds for injecting moulding and possibly reducing the size of the air filter. However, the group appreciated that a smaller size would impact the performance of the engine and due to Honda's mass production and economies of scale, neither of these improvements would have a measurable impact.

Working in groups, researching, deconstructing, documenting, communicating, designing, and interacting with the instructors allowed students to take part in active knowledge construction and aided in the development of their inter-personal skills (Tynjälä, 1999; Yang, 2019). The complexity of the device introduced this early in the student journey ensured students were not focused on their technical disciplines but rather the task at hand. It is noteworthy that the groups were discipline specific; this is largely due to timetabling conflicts. The authors feel that interdisciplinarity could be enhanced by creating mixed discipline groups, something that NTU students undergo later in their first and second years. As is normal with group working, some members contributed more to the group project in some groups and an attempt was made to mitigate this using peer assessments. A more robust assessment method is being deliberated on to ensure that all members of a group take part in all tasks of the project.

Technician perspectives: Hand tools used during the deconstruction of the engines were ratchets with 10, 12mm and 19mm sockets, 10mm spanners, 21mm spark plug sockets and a strap wrench. The use of tools was taught by technicians to each group so that groups had a more personal experience on how to safely use equipment around them. When reconstructing, the use of a piston ring compressor was also introduced. Demonstrations of the piston ring compressor was carried out by a technician and then the groups had the opportunity to use it if they wanted. It was observed that students from the mechanical engineering cohort were more familiar with the hand tools provided while biomedical engineering students needed more support. This is suggestive that the use of hand tools is more relatable for students who might have been enrolled in technical degrees such as BTECs. Students come into university with varying levels of talents and dispositions (Thomas & May, 2010). Introducing the engine in their first term of teaching ensures they develop key skills early on in their student journey, which can be used in various other modules as they go through the engineering curriculum. As an example, the NTU Engineering Grand Challenge is an annual event where students in year 1 and year 2 work as a group and apply their knowledge and skills to propose a creative solution to contemporary grand challenges. Learning how to work in a group and using different tools within the Reverse Engineering Project helps students come out of their comfort zone. Simultaneously, it ensures students understand how to use tools safely so that they observe safe working practices inside the laboratories and workshops. These skills carry through their entire student journey and are continually improved. Moreover, while working on the CAD model of the engines, student's modelling skills are improved which enables them to produce higher quality and more accurate models. Part of the CAD modelling within the Reverse Engineering Project involves producing technical drawings which allows technicians to better visualize what the students intend to manufacture and in turn makes manufacturing easier and more efficient. This clarity in communication between design and manufacture is an explicit expectation in an industrial setting.

By assisting on this project, the technical team gained an insight into the level of competency students come into university with. Much like the students, the skills of the technicians involved also varied. Technicians from a biomedical or sport engineering background needed extra support in using hand tools when originally deconstructing the engine in preparation for the module; this is partly because hand tools are not as regularly used in these disciplines as compared to mechanical and electrical engineering. During the preparation of this project, the technical team had to learn how to read and interpret official documentation for engines. As engines have not been used before, new hand tools and measurement tools had to be procured and all technicians were then trained in the use of micrometres, strain gauges and feeler gauges. The technician competency in the use of these tools was further improved by teaching the students on how to use them. The overall competency in the use of measurement tools improved when showing the students how to use the equipment. Technicians were also able to observe students using these tools and were able to appreciate the difficulties and challenges faced by the students. Technicians also observed what tools were used frequently and which components were prone to damage, enhancing the technical team's resource management skills.

Due to the nature of the project, technicians worked quite closely with the students in the practical sessions, allowing them to further accommodate the students. As an example, if a student was struggling with a specific tool, the technician could provide training instantly and the student applied this training right away, therefore reinforcing the learning undertaken. Another example is when the technicians observed that the provision of labelled bags for the engine components allowed students to better understand and compartmentalize engine components. This is an important observation as moving forward, technicians can repeat the same practice for other larger, project-based modules.

Student feedback: Technicians work closely with the students but are not always seen as instructors (Winberg, 2021) like academics can be, so students tend to give more honest feedback. Student feedback varied through this module; at the beginning students were apprehensive about starting such a big project but excited to try something new. As the module went on, they gained more understanding of why the project was given to them. As an example, initially some students from biomedical and electronic engineering became slightly frustrated that the task at hand was too complex and 'irrelevant' to their disciplines. By the end of the project, the same students were proud of what they had achieved and how much their CAD and critical skills had improved. One electrical engineering student commented to a technician "I would never have thought that 2 months from the start of the module, I'd be this good at CAD!". In the past, students have rated this module quite highly and have given praise for how practical the module is. They felt there was always something to keep them busy during the 2-hour sessions and felt that it had prepared them more for the next term. More importantly, students felt the module had given them an insight into what industry might be like for them. The module received favourable responses in the end of year module evaluation survey. 89 students completed the evaluation and gave an average score of 4.7 out of 5 for "Overall satisfaction" with the module. However, there were some parts of the project that students didn't like as much, such as the lack of research support around the bill of materials. Technicians supporting the module have taken this on board and have considered providing some links to the places they procure materials from so that students can see real life costings of material from vendor websites.

CONCLUSIONS

The methods and discussion presented here demonstrate how CDIO implementation led to meaningful learning for engineering students. The presented project's learning outcomes and delivery methods ensured that the students were engaged in a way that the reinforcement of disciplinary silos was minimised, and the students gained a myriad of skills. The skills included (but are not limited to) teamworking, use of hand/measurement tools, efficient use of CAD, research, project management as well as documentation and professional reporting. Student outcomes presented here are a testament to the emphasis of environmental, social, and economic sustainability adoption through the entirety of the project. Involvement of the technicians early on in the development of the project delivery enriched the learning experience for the students and helped enhance the competence of the technicians and the module leader. Some examples of enhanced faculty competence include time and resource management. Increased technician involvement meant documentation for engine deconstruction was comprehensible for the students.

Based on delivery experience and student feedback, some suggestions for improvement include offering more support to the students in creating a bill of materials by providing a list/ website links of approved material suppliers. Technicians also aim to create video tutorials that demonstrate the use of hand and measurement tools to ensure students are given autonomy and do not rely on technicians for demonstrations. It is suggested that mixed discipline student groups should be formed to further minimise the reinforcement of disciplinary silos and a more robust method of assessment must be adopted to ensure all students engage equally with the project tasks.

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ENGINEERING MINOR IN ARCHITECTURE, A MODEL FOR INTERDISCIPLINARY SPECIALIZATION AND CONTEXTUAL LEARNING

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ABSTRACT

At NTNU, the Faculty of Engineering and the Faculty of Architecture and Design have created a learning environment promoting collaboration between architecture and civil engineering students over the past ten years. Between 2019 and 2021, a Minor in Architecture program for students following the Master's Degree Program in Civil and Environmental Engineering has been piloted, evaluated, and established. The Minor in Architecture program is firmly anchored at both faculties and has become a productive arena for innovative, interdisciplinary, and contextual learning. Within the Minor in Architecture program, students and teachers work closely together, and architects and engineers from acknowledged professional practice contribute with project presentations and guidance. At NTNU, all Master of Science programs include 30 ECTS credits of elective courses in fields outside the core curriculum. The formal structure of the Minor in Architecture is a 30 credits course package consisting of four 7.5 ECTS credits courses within or closely linked to the field architecture. The NTNU Minor in architecture is an arena for collaborative and contextual learning, not only for the architecture and engineering students but also, noticeably, for the academic staff. Considering the necessity of integrating societal aspects for a sustainable world in undergraduate education, we are confident that the NTNU Minor in Architecture is a structure with huge potential to be linked to a wide range of study programs at NTNU.

KEYWORDS

Curriculum development, integrated design-build-test experience, work relevance, faculty development. Standards: 2, 3, 5, 6, 7, 8, 9, and 10.

INTRODUCTION

Both historically and in today's professional practice, architecture is a discipline that is closely connected to many engineering topics. Throughout the 115-year history of the Norwegian University of Science and Technology (NTNU), there have existed many forms of collaboration between architects and engineers. The collaborations, however, have been limited to individual courses without overarching formal frameworks. During the past ten years, there has been a new development in interdisciplinary collaboration between architecture and civil engineering education. The Faculty of Engineering (IV) and the Faculty of Architecture and Design (AD) at NTNU have established a teaching environment promoting collaboration between architecture and civil engineering students. Research reflecting these interdisciplinary collaborations between architecture and civil engineering education has been presented previously (Manum and Sandaker, 2010; Manum and Sandaker, 2011; Rönnquist et al., 2019). As a further development of this interdisciplinary learning arena, the IV and AD faculties have collaborated on the Minor in Architecture program as a pilot project in NTNU's testing of Minor arrangements, aiming at formalizing interdisciplinary education. The main aim was to create a richer and more work-relevant context for students. The approach consisted of creating, or gathering, a set of courses where students from the two programs work together in design of buildings and structures, including the opportunity to carry out a Design-Build-Test (DBT) capstone project in collaboration with various practices in the community. The course package was created within the format of electable courses by the students of the Master program in Civil and Environmental Engineering. All of the courses in the package have AD as their host faculty.

By choosing a package of courses in architecture amounting to 30 ECTS and framing this in the format of a Minor, the NTNU-system of elective courses was applied to provide the option of deepened competence in a particular supplemental discipline. No new administrative measures were needed, other than identification of suitable existing elective courses and supplementing with one new. The program has been offered to students in the 5-year Master program in Structural and Civil and Environmental Engineering and is now being continued from the pilot period.

Teaching-learning activities in architectural design have two characteristics that distinguish them from civil engineering education. One is the focus on the context-specific design of particular solutions. The second is the focus on conceptual thinking – on the need for preparation, testing, and clarification of overarching guidelines or frameworks, which is crucial for the sum of many individual choices to result in a solution that appears as a meaningful whole.

In the strategy work on Future Technology Studies (FTS), "Technology Education 4.0: Recommendations for the development of NTNU's technology studies 2022 – 2030," NTNU has highlighted the importance of context-oriented planning, training in conceptual thinking, and project tasks related to real and complex issues, as important themes for strengthening the engineering education (Øien and Bodsberg, 2022; Øien et al., 2022). These are precisely the elements that are essential in architecture education. NTNU's Minor in Architecture program for Engineers aims at developing an arena for collaboration between the subject areas in teaching so that these elements from architecture education can be further developed and included in the civil engineering student's knowledge and skills.

This paper presents the design of the Minor in Architecture program and the impact it has had on the competence of both architecture and engineering students and their teachers. We discuss the Minor in Architecture program as a model template for integrating both work-place relevance and courses from two study programs in a contextual learning environment.

METHODS

The education design within the Minor in Architecture program consists of three core elements. First, it encourages an interest in and understanding of architecture as a common interdisciplinary knowledge base. Second, it enables an insight into the practice of the architectural profession with concept-based and context-specific architectural design. Third, it fosters experience-based competence in building design as an interdisciplinary arena and how to contribute to this arena as engineers.

Experience has shown that many students from the Master's Degree Program in Civil and Environmental Engineering and the Master's Degree Program in Architecture at NTNU have an interest in both fields of study, and before being accepted to their respective programs were in doubt whether to choose to apply for one or the other study program. In professional practice, the fields engineering and architecture are closely linked to the mutual benefit of the actors within the respective disciplines. This, however, is often not the case within today's sphere of education. Thus, opportunities for development of knowledge and skills vital to operate in a beneficial way as a professional engineer are not exploited.

With this as a backdrop, as an attempt to fill this gap, one of the aims of the Minor in Architecture program at NTNU is to maximize the potential of students' abilities and interests outside the parts of their study programs defined as "crucial for learning outcome." Elaborations on the particular methods manifesting these aims are to be found in the ensuing sections.

Structure and Content of the Minor in Architecture Program

The Minor in Architecture program utilizes the potential of electable courses within the Master's Degree Program in Civil and Environmental Engineering. Such electable courses are viewed as decisive for the program's overall learning outcome with regards to the establishment of an interdisciplinary specialization. This interdisciplinary specialization is responding to demands from dedicated students, as well as to society's need for knowledge and skills concerning the application of subject-specific competence onto the complex issues of building and structural design.

NTNU has a study program structure where 30 out of the 120 ECTS credits worth of courses during the final two years of Master's degrees are electable. These 30 ECTS electable course credits must be chosen outside the students' own field of study, supporting interdisciplinary studies. NTNU has defined a Minor program – in general – as a package of courses within a field of study that must be outside the field of study of the main program, in a way such that the former supplements the latter. Following this overall structure, the Minor in Architecture program is organized as a course package consisting of four 7.5 ECTS credits courses in the field of architecture. The courses within the Minor are given during the 7th, 8th, and 9th semester of the Master's Degree Program in Civil and Environmental Engineering. Throughout the course of the pilot, the number of students admitted to the Minor in Architecture program has been limited to 12. According to the Study Program Description of the Master's Degree Program in Civil and Environmental Engineering about 170 students are admitted each year. The percentage of the students of the Program choosing the Minor in Architecture program is about 7 %. The actual numbers of admitted students for each pilot cohort has been 12, 12, and 11, in 2019-20, 2020-2021, and 2021-22, respectively. Based on the interest from engineering students within parts of the field outside structural engineering, the 12 student limit will be omitted from the fall semester of 2023. The expected number of students admitted to the Minor in Architecture program the fall semester of 2023 is about 20. Thus, after the implemented change, the percentage of the students of the Master's Degree Program in Civil and Environmental Engineering choosing the Minor in Architecture program is expected to be about 12 %.

Students are admitted to the Minor in Architecture program by applying to one of the two mandatory courses of the program called “Introduction to Architectural Design for Engineers” (Course 1), which is a new course designed for the Minor program in particular. This course runs across all three semesters of the program, functioning as its administrative framework, e.g., allowing communication between teachers and students, and information about program-related arrangements, etc. Additionally, during the final semester of the program, i.e., the 9th semester, the course contains elaborate teaching where students from both the Master's Degree Program in Civil and Environmental Engineering and the Master's Degree Program in Architecture work together on architectural design projects in studios. As an integral part of this course joint seminars are arranged for all the Minor in Architecture students. These seminars typically feature practicing architects and engineers presenting their professional work.

Course 2 of the Minor is a 7.5 ECTS credits course called “Architecture as a Technological Practice” during the 7th semester. This is the second of the two mandatory courses of the program. This course emphasizes the relationship between architecture and scientific and technological development. With a historical lens, it aims at enlightening the students regarding their own role as professionals within the broader context of interdisciplinary collaboration towards common aims of design and construction of buildings.

Following the NTNU-structure of elective courses, course 3 of the Minor is an electable course in engineering that can be chosen from any of the other engineering programs at NTNU. For the Minor students, this course is chosen among those offered by the AD faculty. Course 4 of the Minor is “Experts in Teamwork” (EiT), a mandatory course at NTNU for all Master students, regardless of program, where the students work in interdisciplinary teams on real world projects, with detailed and explicit intended learning outcomes for personal and interpersonal skills using active and experiential learning approaches (Wallin et al., 2017). The students choose one of the EiT courses with an architectural theme. The most popular of the EiT courses are “Architecture for Non-Architects,” “Improve Your City” and “Future Wood.”

See Fig. 1 for a visualization of the structure of the Minor in Architecture program. For a more detailed description of the structure and three courses of the Minor in Architecture program, see the paper presented at the Fifth International Conference on Structures and Architecture, ICSA 2022 (Taraldsen, et al., 2022).

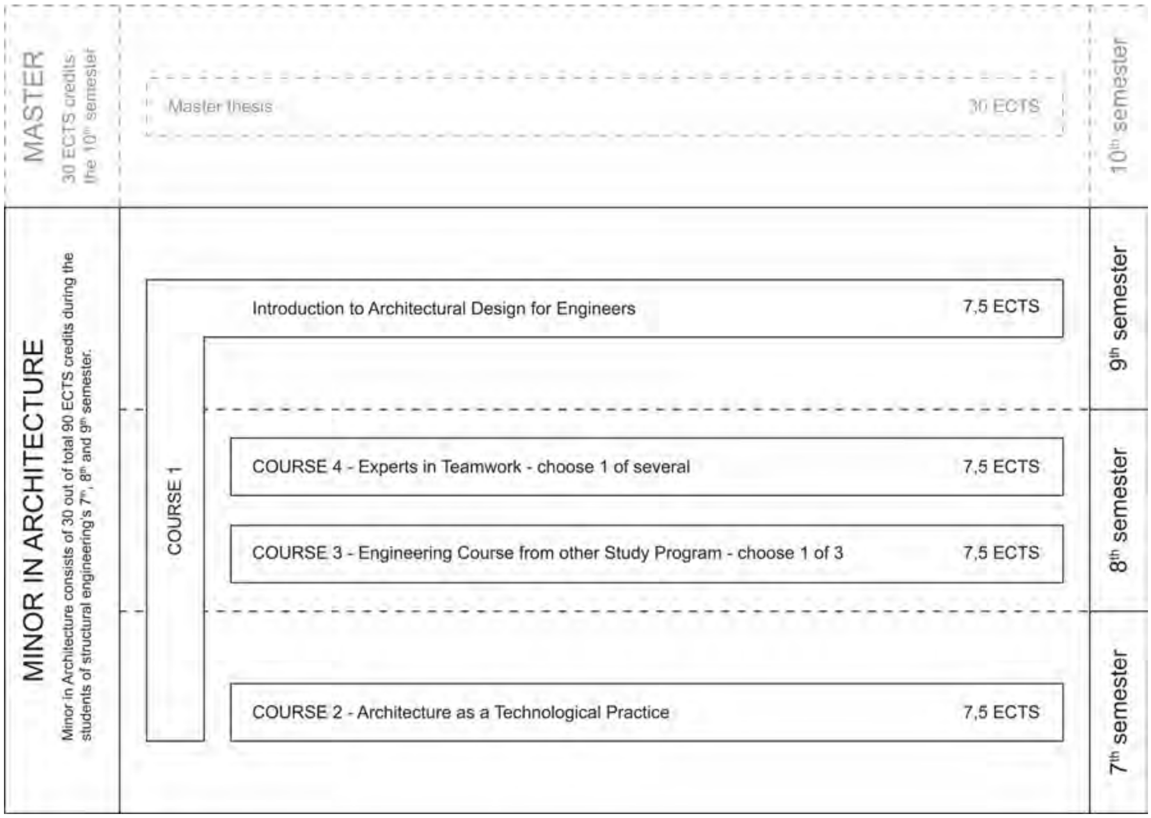

Figure 1. The structure of the Minor in Architecture program.

An essential element of the Minor in Architecture program's learning environment is that the students are learning from each other. This happens through direct collaboration between students of architecture and civil engineering in the design studios supplemented by group work on digital platforms. Another essential element is that the students across cohorts (as the program runs for three semesters, two cohorts overlap in the autumn semesters) continuously inform each other about the contents and learning outcome of the various courses within the Minor in Architecture program, which also serves as a consultancy practice for electing courses.

Academic staff at both faculties (IV and AD) contribute to the teaching in the courses constituting the Minor in Architecture program, especially concerning supervision of the students' architectural and structural design projects Particularly important in this respect is the course "Introduction to Architectural Design for Engineers." Interdisciplinary teaching-learning activities are present throughout the program, exemplified in a clear fashion in the course "Structural concepts in architectural design, models and methods," where engineers and architects from prominent international offices participate in both project supervision and presentations from their own architectural practice, with special emphasis on conscientious collaboration between architects and engineers that has led to innovative structures and highly acknowledged architecture.

In order to ensure quality and develop the scheme of the Minor in Architecture program, reference groups, consisting of students in the course, and joint meetings are actively used to evaluate the individual students' disciplinary development, as well as how the courses of the Minor in Architecture program contribute to the overall learning outcome within the scope of their respective Master's Degrees in Civil and Environmental Engineering.

RESULTS

The scheme is rooted in both faculties (IV and AD) and has become an arena for innovative, interdisciplinary, and contextual teaching-learning activities. Students and lecturers from Faculty of Architecture and Faculty of Engineering work closely together, and architects and engineers from acknowledged professional practice contribute with project presentations and with supervision. By way of this, the students of engineering develop experience-based competence in the tacit knowledge of design practice, while the students of architecture get experience in discussing and developing architectural design project in collaboration with competence outside their own field. For both the architecture and the engineering students, this is highly relevant for their future professional practices.

Concerning the competence developed by the engineering students in the Minor program, there are three noteworthy aspects. First and foremost, the Minor in Architecture program shapes the students' thinking not only about architecture, but also, and more importantly, how they think within their own discipline of engineering. When we compare engineering students that have undergone the Minor in Architecture program with their fellow students who did not, we observe that the former have become skillful in developing context specific design proposals and in discussing, evaluating, and developing these in insightful ways, including both structural and architectural concerns. What we observe, is that the Minor in Architecture program not only strengthens the students' abilities to oversee and solve structural design tasks but also their ability to see the engineering tasks in broader contexts and devise solutions that respond to complex issues. The students have via the reference group reports confirmed this, for instance, the 2021-22 cohort noted that "it was also very instructive to work with architects who could teach us about concept development."

A second aspect is what the students have learnt from participating in the design processes in the architectural design studio classes – a frame of thinking and working very different from what they know from their Master program in engineering. Key elements are the focus on conceptual thinking, essential in the architect's education but more or less absent in the education of engineers, and the context specific approach of architectural design. This has been confirmed by the students in the written reference group reports. For instance, the cohort of 2020-21 stated that "[the] best learning outcome, [was from] guidance in the classroom with the group."

Finally, learning about architecture in terms of key buildings through history, has provided insight into the close links between architecture and engineering, and new perspectives on the background of their own discipline of engineering. This, too, is supported by formalized feedback from the students, e.g., the cohort of 2020-22 wrote that course 2 "was good for learning about buildings and architects that you can refer to in the later subjects, especially in the context of the Minor, but also otherwise."

As mentioned in the introduction, the Minor in Architecture program is not a project developed from scratch, but a development and a formalization of existing collaborations between educational scholars and professional practice bridging the disciplines of architecture and engineering. An inspiring outcome of the Minor in Architecture program is that the collaboration between the two faculties has provided new contacts and interest across the disciplines for many scholars at the concerned departments at respective faculties. Most importantly, these are scholars at the Faculty of Architecture and Design hosting the engineering students in the design studios, and scholars at the Department of Structural Engineering teaching structural engineering courses collaborating with courses at Faculty of Architecture and Design.

The collaboration between the faculties in organizing and teaching the Minor in Architecture program has also initiated further collaboration and development of curriculum. The Minor in Architecture program situates competence by way of applying knowledge and skills in realistic and complex contexts at the center of the student's learning. This is what makes the Minor scheme particularly innovative. One example is that the Department of Structural Engineering this year, for the second year in a row, is taking part in teaching in first class at the Master in Architecture program. A second example is how the engineering students at the final course of the Minor in Architecture program present architecture-relevant knowledge about structures and construction materials to the entire second year class at the Master of Architecture program. A third example is the projects course of the 9th semester at the Master in Civil Engineering, where the design task for the past two years has been to design footbridges in collaboration with the municipality of Trondheim. This is an interdisciplinary capstone project which provides the students with ample opportunity to apply the expertise acquired through the Minor in Architecture program to a structural engineering design that offers solutions to several issues of urban complexity. In parallel to and in collaboration with the bridge design course at IV faculty, two students of architecture chose one of the footbridges as task for their architectural design course. By collaborating with engineering students at a Minor in Architecture course the previous semester, the architecture students had built a strong background concerning the unification of architecture and structural design, and their bridge proposal was astonishing, uniting context specific architectural concerns with advanced structural analyses in a way that neither of the two approaches would have managed alone, see Fig 2.

Figure 2. Bridge design project by students of architecture Andre Berlin and Krzysztof Jan Pietura at 9th semester, fall 2022. (Photo: Bendik Manum)

DISCUSSION

The Minor in Architecture program integrates deep subject knowledge and contextual learning with problem solving in an environment characterized by interdisciplinary collaboration and provides both civil engineering and architecture students with insight into building design as a collaborative arena for the architecture and engineering professions. The engineering students gain new perspectives on the relevance and potential of their engineering field and an understanding of their own field's contribution to architecture, both historically and in the present.

New perspectives emerge as the students develop experience-based competence in conceptual thinking and building design in an interdisciplinary arena. By working together with students of architecture in design studios, and through the course on the history of interaction between engineering and architecture, the engineering students develop interest in and understanding of historical and contemporary architecture as references and a knowledge base not only for architecture but also for their own particular discipline of engineering.

An additional and unexpected benefit of the Minor in Architecture program is that the teachers from both study programs are able to put their students' education in a broader professional context. It is a common problem in higher education that teachers to a large extent focus solely on their own field, and thus risk neglecting the students' need to apply field-specific skills and knowledge to wider contexts. Architecture and civil engineering are professions that are in close collaboration in practice, making it desirable that the teachers have a firm understanding, not only of the profession the student's education is aimed at but also of adjacent professions.

The connection to practice, the collaboration between the students and the scholars from both study programs, in addition to important contributions from highly acknowledged professional practitioners, makes the Minor in Architecture program highly relevant and desirable.

The goal for any five-year Engineering program is that the matriculated students will be highly competent to assume demanding professional roles. The sought-after competence is far more than the mere sum of the knowledge and skills acquired in the separate courses throughout their education. It also requires the ability to determine which knowledge or skills that are relevant, and when it is necessary to bring in competence from actors outside their own discipline, in order to meet real-world challenges. Real-world challenges are often characterized by numerous conflicting boundary conditions, such as, e.g., sustainability issues, budget constraints, and legal frameworks, as well as potential ethical challenges, sometimes challenging to the extent that they are characterized as “wicked problems” (Lönngren & Van Poeck, 2021)

A key value of this Minor in Architecture program, and the reason why its framework is applicable to other disciplines, is the course design that links a set of elective courses together into a Minor, providing knowledge and skill in a complementary field of high relevance for the master program. This includes the feature of building the Minor around a central course unit , which in the case of Minor in Architecture is the course “Introduction to Architectural Design for Engineers”, a course that provides the opportunity for an interdisciplinary capstone project, anchored in both society and professional practice.

Reflecting on the Minor in Architecture program in the context of the CDIO Standards, we believe that the established Minor illustrate many of the CDIO Standards. The Minor increases depth and context for both course and program learning outcomes (Standard 2). The Minor aims to integrate knowledge and skills in several relevant contexts (3), and make use of examples of design-implement experiences (5), and of engineering learning workspaces (6). The course design is characterized by integrated learning experiences and by active contextual learning (7 and 8). Of additional interest is that the Minor construction also addresses Standard 9 and 10 – Faculty Competence and Faculty Teaching Competence, by creating a joint interest in the Minor for teachers from both programs, thus providing a fertile arena for setting subject knowledge and skills in a wider work relevant context. While the CDIO Standards are formulated from an engineering perspective, it should be pointed out that the corresponding aspects also conversely apply to architecture study program and the teachers on that program.

CONCLUSION

While the Minor in Architecture program at NTNU responds to students' demands and develops competencies in demand in working life, the scheme inspires the development of interdisciplinary competence among teachers in both disciplines. The Minor in Architecture program has extensive potential for development for architecture aimed at disciplines other than civil engineering, and as a model for interdisciplinary teaching between other disciplines. The latter applies at NTNU and at all universities with strong professional environments in various disciplines.

The Minor in Architecture program has become a basis for collaboration between architecture and engineering and can serve as a model for course structures supporting integration of joint work relevant for several other programs and across other disciplines.

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ADAPTING ENTREPRENEURSHIP TECHNIQUES FOR CREATIVE TECHNICAL COURSE DESIGN

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ABSTRACT

Innovation and creative capacity are integral skills for the development and training of engineering graduates. Traditionally, creativity is predominant in design-based courses, rather than technical engineering or science courses, despite the need for students to apply creative problem-solving to technical challenges. This paper describes the development of a course design architecture for designing technical postsecondary courses with embedded learning outcomes in creative thinking. The proposed framework adapts techniques traditionally used in entrepreneurship and business development and considers how they may be used to address the CDIO standards in both course and curricula design. This work includes the CDIO-informed adaptation of an innovation toolkit model for post-secondary course design, considering how elements such as customers, team members, value proposition, and product offering have similar parallels to post-secondary education. The use of a structured course design architecture for teaching creativity within technical courses allows instructors to consider the educational needs of students and industry. The proposed framework adapts a mapping tool used for entrepreneurial product development, requiring course designers to consider the outcomes for their intended users, the strengths of their team, the goals of their course, and the potential pains or gains of their course offering. These planning aspects complement the CDIO standards, in particular the identification of CDIO context, planning of learning outcomes, integrating across curricula concepts, and designing and implementing learning experiences. The results of two implementation case studies are described in the context of electrical and software engineering education. The first case study is a fourth-year technical elective in designing algorithms. The second case study is a first-year computing course. Both courses showed higher levels of engagement and better learning outcomes after the implementation of the proposed changes. Results demonstrate how courses can be improved through this entrepreneurship planning model to include more creativity, application, and innovation, while adding value to technical courses without impacting the required domain knowledge learning.

KEYWORDS

Curriculum design, course design, change, creativity, framework, Standards: 2, 3, 7, 9, 12

INTRODUCTION

Innovation and creative capacity are integral skills for the development of engineering graduate attributes. As graduates face new and increasingly interdisciplinary world challenges, curriculum designers must adapt and develop courses that teach technical domain knowledge as well as expanding student creative capacity (Kelly, 2016; Atwood & Pretz, 2016; Genco, Holtta-Otto & Seepersad, 2012). Leading companies such as Google, Intel, and Microsoft are even investing their own resources in educational development in an attempt to cultivate future engineers capable of integrating technical knowledge and critical thinking in creative applications (Google, 2023; Intel, 2023; Microsoft, 2023).

In many engineering programs, students are expected to develop their innovation and creativity through open-ended introductory and senior design courses, while technical courses remain focused on domain knowledge. The learning outcomes of most postsecondary engineering courses are centered around technical concepts, rather than creative application and development. This is despite a growing need for postsecondary institutions to develop agile curricula capable of adapting to global changes (Brink, Carlsson, Enelund, Georgsson, Keller, Lyng, et al, 2023). While instructors may value creativity, it can be difficult to integrate effective creative thinking pedagogy within a technical course. In addition, a lack of focused change management may result in instructors encountering barriers when attempt to redesign large scale courses or integrated curricula, including challenges around workplace realities and limited collaborative culture (Taylor & Mannis, 2008).

Literature shows a clear need for creativity to be a greater focus in engineering (Felder, 1988; Charyton, Jagacinski, Merrill, Clifton & DeDios, 2011; Robinson & Azzam, 2009). This paper will describe the development of a course design architecture for designing technical postsecondary courses with embedded learning outcomes in creative thinking. The proposed framework adapts techniques traditionally used in entrepreneurship and business development and considers how they may be used to address the CDIO standards in curricula design. This study will detail the CDIO-informed adaptation and implementation of an innovation toolkit model for post-secondary course design, considering how elements such as customers, team members, value proposition, and product offering have similar parallels to post-secondary education.

BACKGROUND

The CDIO standards are built on a foundation of design, implementation, and feedback cycles. Effective adoption and implementation of the standards requires cooperation among varied levels of stakeholders, design and assessment of appropriate learning outcomes and content delivery, and continual improvement processes. Standards 2 and 3, for example, require curriculum and learning outcomes to be aligned not only at a course or program level, but also with faculty and industry stakeholder goals. Educators and administrators may find the design and implementation process overwhelming while also being faced with the change management challenges common across postsecondary institutions, such as budgetary constraints, large class sizes, lack of space, and peer or student resistance. Lack of alignment between graduate attributes and desired competencies is also an ongoing problem in engineering education (Ormazabal, Serrano, Blanco, Carazo, Aldazábal & Azasu, 2022). Considering whole-system improvement helps to support the drivers of educational change (Fullan, 2015). Dedicated planning tools allow curriculum and course designers to adequately assess potential challenges and possible solutions.

Entrepreneurial planning tools allow innovators to design and develop their ideas for products, services, and other offerings before expending valuable time and resources. Just as an entrepreneur plans their business strategy, a course designer needs to consider the stakeholders and desired outcomes of their educational initiatives. From flipped classrooms to experiential learning activities, the selection of pedagogical techniques can be overwhelming. Course designers may also be faced with institutional expectations and logistical limitations. The use of a structured course design architecture for teaching creativity within technical courses allows instructors to consider the educational needs of students and industry. While some entrepreneurship models have been used to develop the outcomes of entrepreneurial learning itself (Bruton, 2010), there remains opportunities to incorporate these concepts in engineering education, particularly for the integration of creative thinking and capacity development.

The Idea Model is a planning tool offered by the Straight Up Business Institute and provides entrepreneurs with a visual map for brainstorming, analyzing, and iterating on a cohesive business plan (Straight Up Business Institute, 2023). The map centers around three target areas: **People**, **Customer**, and **Offering**. These areas also overlap with one another to create intersections: **Distinctive Competencies** and **Value Proposition**. Figure 1 shows the original Idea Model.

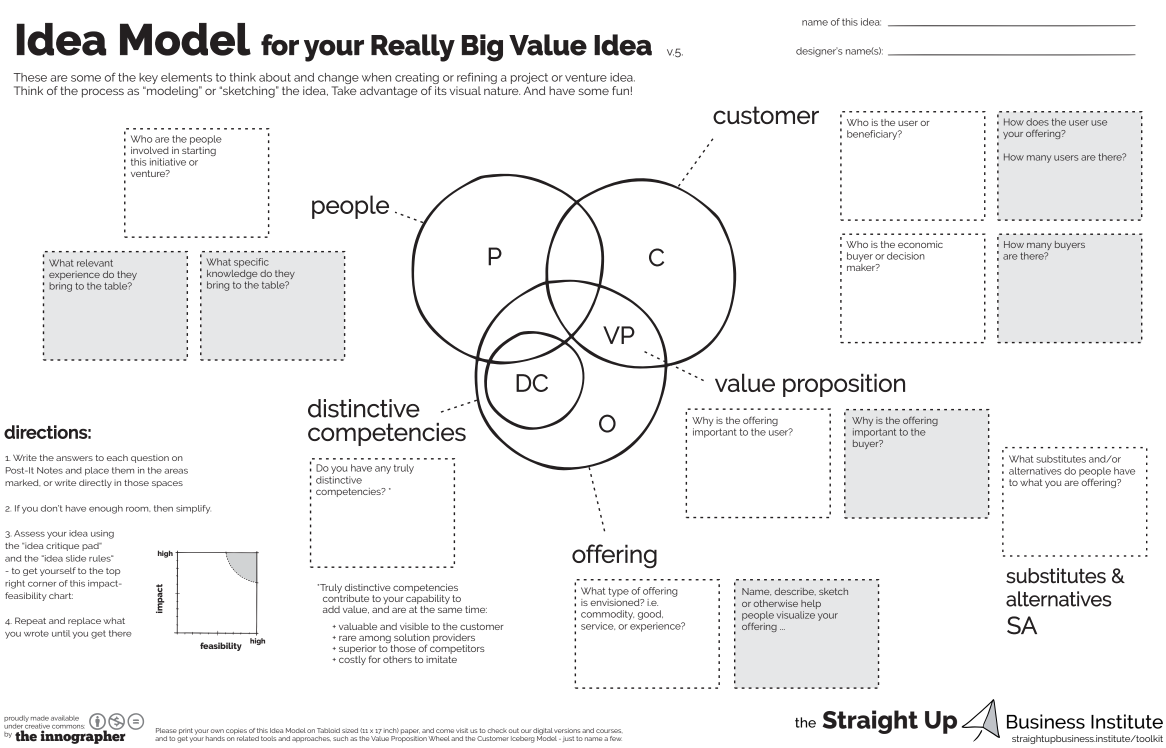

Figure 1. The Ideal Model (Straight Up Business Institute, 2023) is used for entrepreneurial planning.

The value proposition of a business requires careful consideration and balance. There are varied planning tools available to help with value proposition analysis, from financial guides to marketing maps. Strategyzer offers a simple planning tool that allows entrepreneurs to consider the potential problems and benefits of their value proposition (Strategyzer, 2023).

This Value Proposition Canvas visualization, shown in Figure 2, was used to expand on the **Value Proposition** area of the adapted framework.

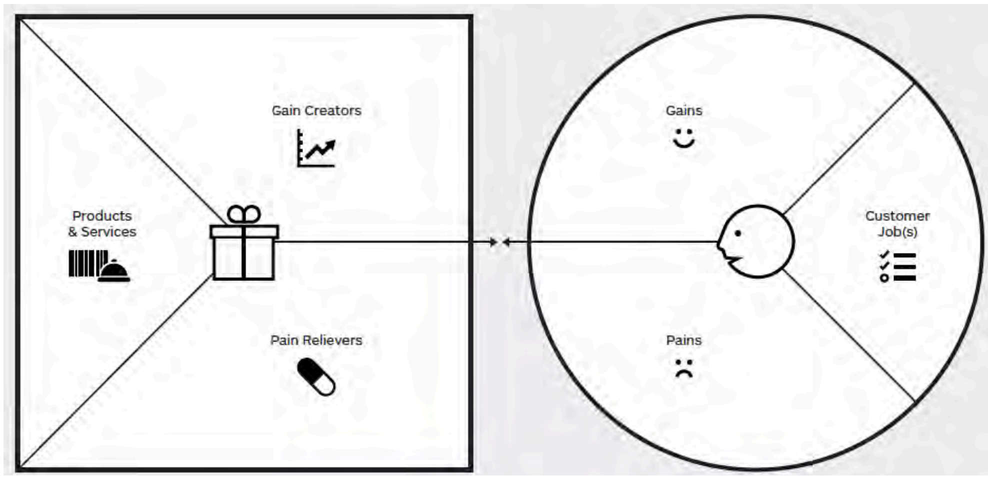

Figure 2. The Value Proposition Canvas (Strategyzer, 2023) balances the pains and gains of an idea.

METHODOLOGY

The proposed framework modifies the Idea Model and the Value Proposition Canvas from entrepreneurial planning tools into useful course or curriculum planning guides. Each section of the tools has been converted to an element that must be considered when developing pedagogy. The framework requires course designers to consider the outcomes for their intended users, the strengths of their team, the goals of their course, and the potential pains or gains of their course offering as they seek to maintain academic rigor alongside creative development. The framework adaptation map can be seen in Figure 3. The overall architecture is shown in Figure 4.

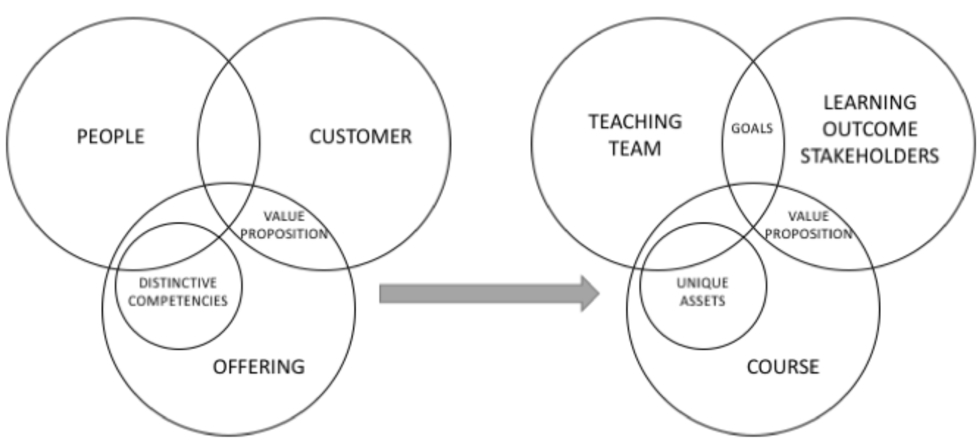

Figure 3. The Idea Model (Straight Up Business Institute, 2023) can be mapped to corresponding pedagogical areas.

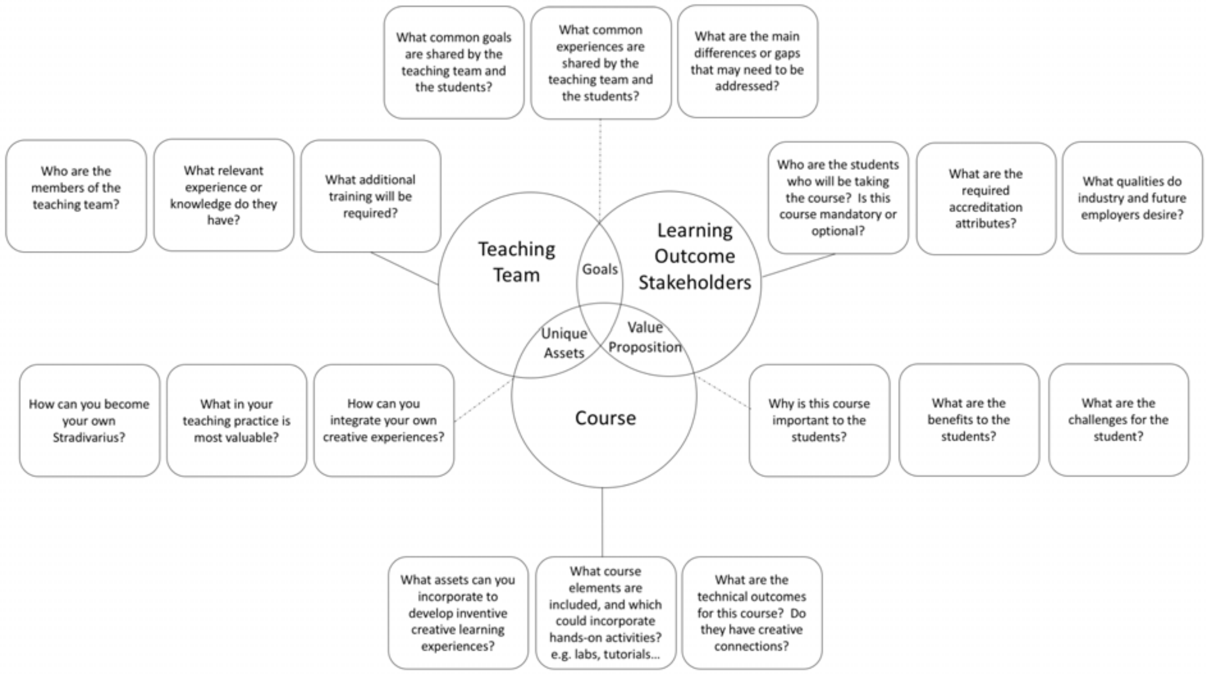

Figure 4. The adapted model allows designers to plan course and curriculum development.

The first main section, **Teaching Team**, requires a course designer to consider the **People** that will be involved in the pedagogical initiative. This may or may not include the course or curriculum designer themselves. Members of the **Teaching Team** could be instructors, teaching assistants, technicians, administrative staff, and even potentially instructors of pre-requisite and subsequent courses. The interactions between the members and their relevant knowledge or experience will help to form the course offering while determining what additional training or support may be needed.

The second main section, **Learning Outcome Stakeholders**, considers the **Customers** of a curriculum or particular course. The intended audience of a course or curriculum design is not always obvious. While students may be the initial audience, the ultimate consumers are the engineering industries that benefit from graduate employees. Decision-makers such as administration and accreditation boards also play an important role in determining educational goals and directions. Together, the target audience for educational design can be called the **Learning Outcome Stakeholders**. Other considerations may include the demographics of the student body, whether the course is a mandatory requirement, the type of available facilities, and other logistical concerns.

The third main section is the **Course** (or curriculum) that will be offered. Business leaders visualize and explain their planned product or offering. In the same way, course designers need to detail all aspects of their planned pedagogy, including the format, duration, learning environment, and types of assessment. There may be opportunities for creative integration within projects or problem-based learning, or the course content might be ideal for a flipped classroom format. Integrating creative learning outcomes with technical learning outcomes requires **Unique Assets** of both the **Teaching Team** and the **Course** to be considered. These are unique abilities and experiences that can be emphasized to create the best possible offering.

There is also some overlap between the **Teaching Team** and **Learning Outcome Stakeholders** of a course or curriculum. This intersection is where the educational **Goals** can be determined. The alignment between the **Teaching Team** and the **Learning Outcome Stakeholders** reveals common experiences and desired outcomes while uncovering disparities or potential gaps in knowledge.

Finally, the **Value Proposition** allows the designer to balance the benefits and challenges of proposed changes, novel pedagogies, or other potentially disruptive ideas. By predicting potential problems or difficulties ahead of time, course designers can attempt to mitigate the issues early in the development process. Likewise, anticipated benefits can also be enhanced during the design phase. Figure 5 shows how the Value Proposition Canvas model can be used in an educational context.

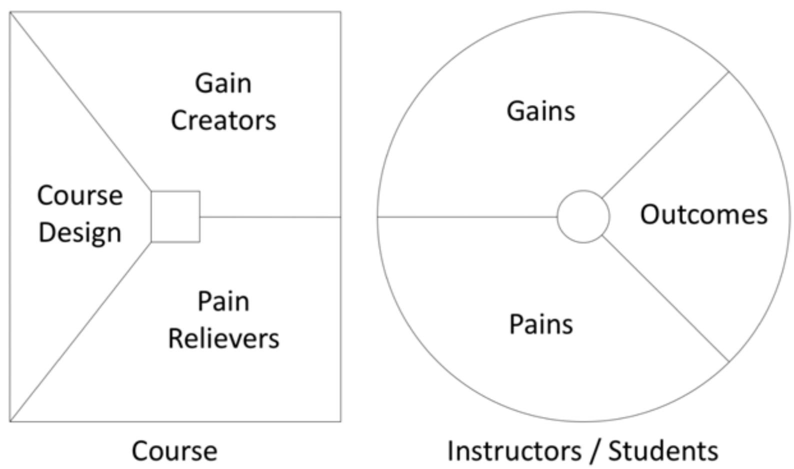

Figure 5. The Value Proposition Canvas (Strategyzer, 2023) can be applied to educational offerings.

IMPLEMENTATION

The adapted framework model has been tested with two different redesign initiatives. The first involved the design of a new creative course project for a senior electrical engineering technical course, ENCM 507. The technical material of this course taught concepts for electronic design automation and algorithms with a class enrollment of approximately 20 students. The second case study was the full redevelopment of a large-scale introductory programming class required by all first-year engineering students. The total cohort enrollment of this course, ENGG 233, was around 800 students.

Case Study #1

With a diminishing course enrollment and waning student interest, the instructor of ENCM 507 decided to implement a creative and engaging course project using game-based learning. Using the adapted framework, the instructor mapped the desired learning outcomes and available resources. She was able to identify gaps in her own knowledge of educational games and subsequently added an interdisciplinary colleague to the **Teaching Team**. Figure 6 demonstrates how the architecture was used to develop the outline of a new project. The instructor also used the Value Proposition Canvas tool, seen in Figure 7, to anticipate the potential issues of incorporating creative concepts, such as storyboarding, and logistical concerns around student discomfort.

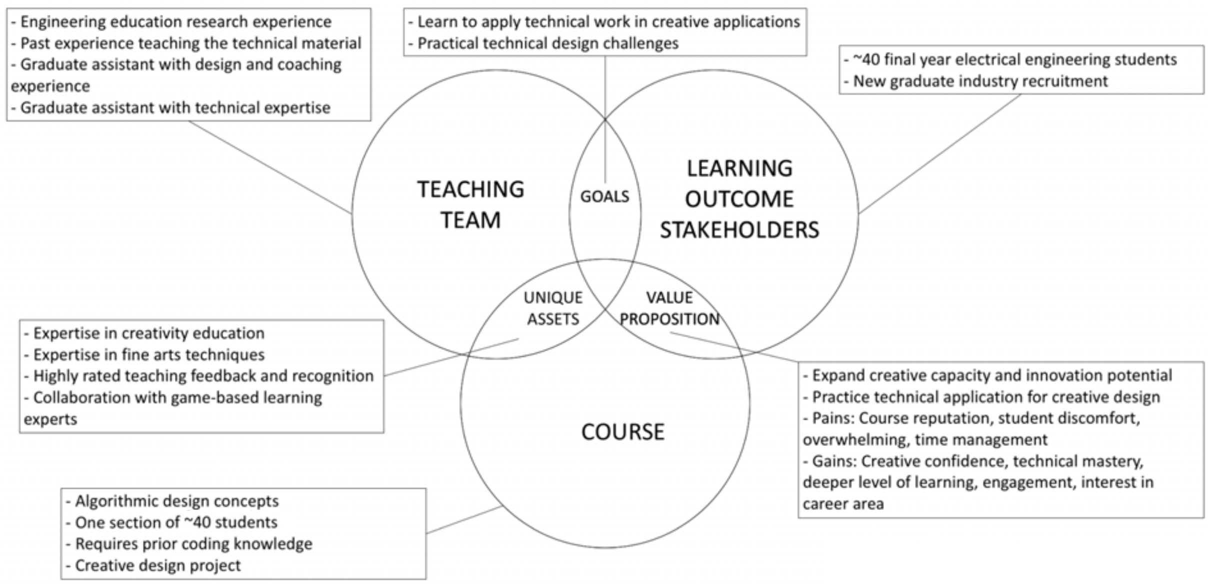

Figure 6. The course design architecture was used to develop a project for ENCM 507.

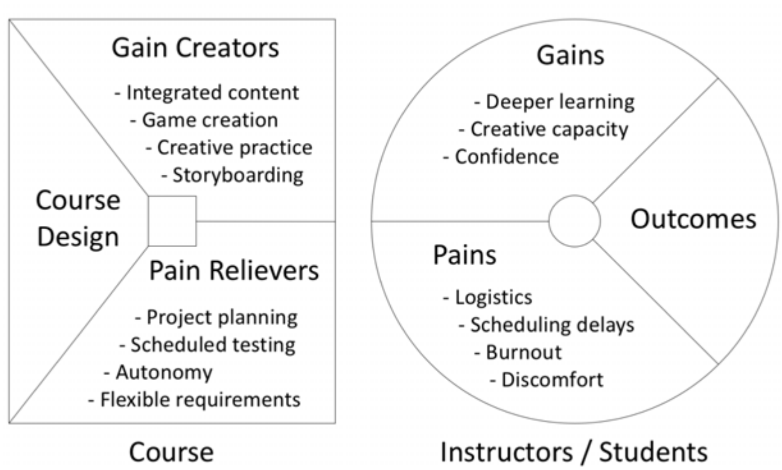

Figure 7. The value proposition of ENCM 507 balances the redesign pains and gains.

Case Study #2

Redesigning ENGG 233 was a larger process that originated from the faculty administration level. Using the framework models allowed all involved parties to better understand the overall goals and cohesive vision. The large-scale enrollment required a **Teaching Team** of two instructors, 28 graduate teaching assistants, and additional administrative support. To incorporate more experiential learning, the instructors took advantage of their **Unique Assets** (startup experience and fine arts experience). They flipped the classroom, turning the lectures into online videos and implementing a studio-inspired laboratory environment. The corresponding planning models can be seen in Figures 8 and 9.

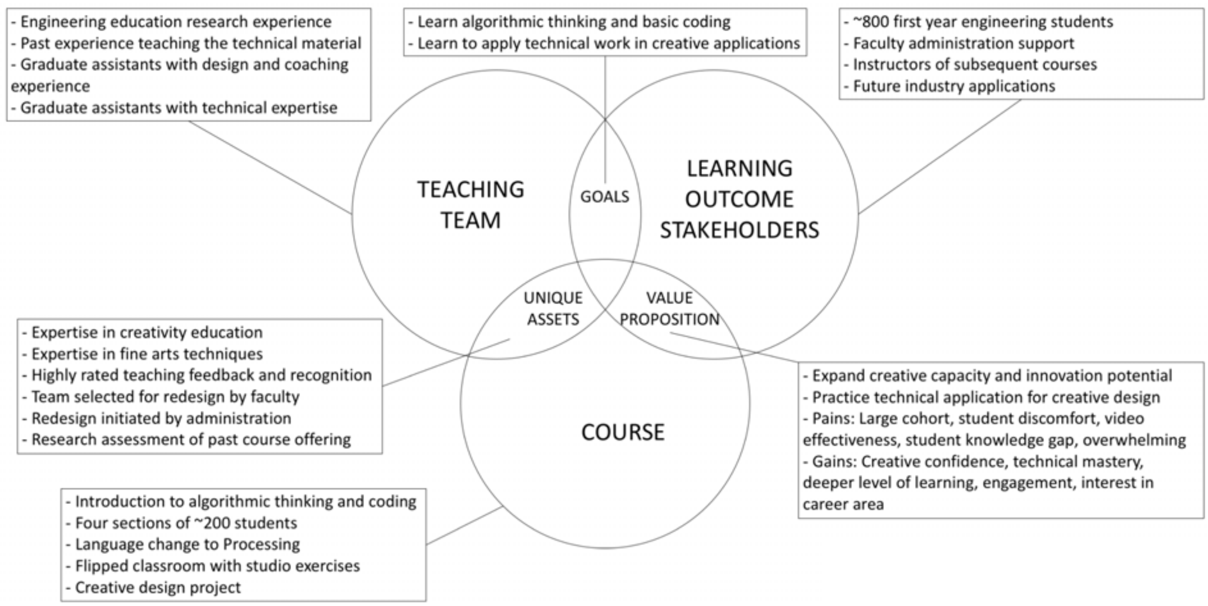

Figure 8. The course design architecture was used to redesign ENGG 233.

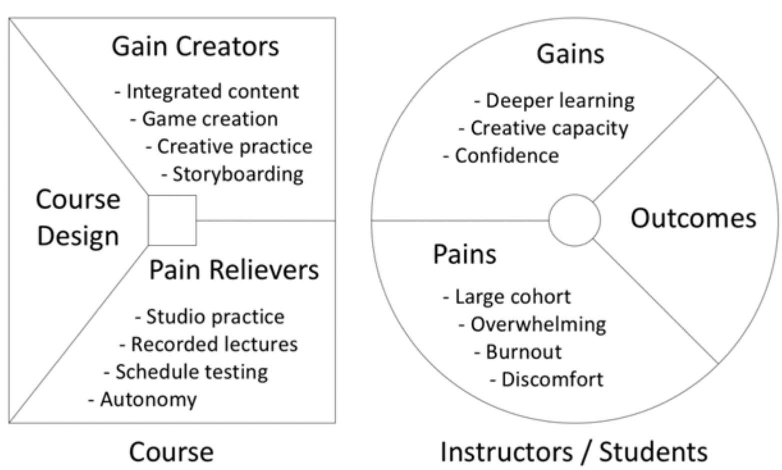

Figure 9. The value proposition of ENGG 233 balances the redesign pains and gains.

Qualitative and quantitative survey questions were conducted in each of the case studies to better understand the impact of the planning tools.

Two years after the creative project was implemented in ENCM 507, interest in the course was renewed. 40% of students in the third offering of the course said that they were motivated to enroll due to recommendations of past students and friends. 60% of enrolled students were interested in game design and 80% were also interested in the technical material. After taking the course, students expressed appreciation for the flexibility and autonomy that were implemented as “pain relievers”. One student said: *“Making and demoing the video game project was the funnest project in any course I've had so far because it allowed for creative expression and problem solving."* The course instructor noticed an improvement in student performance and noted that she was able to shift her exam content from memorized concepts to open-ended design questions. Interestingly, she also reported that the project redesign revealed her own weaknesses in creativity as well.

The ENGG 233 redesign was also studied over multiple years. When compared to the previous course format, students self-reported more enjoyment of programming and improved creative thinking. Technical performance was not impacted by the changes in the course format, and instructors of the subsequent courses did not find a decline in student knowledge, preparation, or performance. The instructors felt that student learning and performance were positively impacted, and that students were able to focus more on project design within the technical course. One instructor commented on his experience with the redesign: *“It is especially important to pay attention to student needs, and carefully study the data to support your design.”*

Both teaching teams continue to use the planning techniques as they iterate and refine their courses.

CONCLUSION

The developed planning framework allows educators to construct a more effective learning experience that incorporates opportunities for students to create and build on their technical knowledge. The results of two implementation case studies showed higher levels of engagement and better learning outcomes after the implementation of the mapped redesigns. The case studies demonstrate examples of how courses can be improved through entrepreneurship planning tools to include more creativity, application, and innovation without negatively impacting the required domain knowledge learning. The developed architecture is used to add value to technical engineering courses by expanding student creative capacity and enriching postsecondary engineering education.

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BIOGRAPHICAL INFORMATION

Emily Marasco is an Assistant Professor (Teaching) of software engineering and the Schulich School of Engineering Teaching Chair in Engineering Education Innovation – Digital Transformation. Her pedagogical research and teaching interests are in the areas of innovation and learning engineering, including the use of data analytics, gamification, blended learning, and entrepreneurial thinking as tools for enhancing creativity and digital literacy within software and computer engineering. Dr. Marasco's research-informed pedagogical practice integrates cross-disciplinary, entrepreneurial aspects with cognitive diversity and creative technical experiences. Dr. Marasco is active as a science communicator and outreach speaker in the local education community. She has been recognized as the 2018 ASTech Outstanding Leader of Tomorrow and as one of Calgary's 2019 Top 40 Under 40 recipients.

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INTEGRATION OF GRADUATE EMPLOYABILITY SKILLS THROUGH INDUSTRY OUTSOURCED CDIO PROJECT

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ABSTRACT

Engineering curricula in higher education should be aligned with the current and future requirements of the industry to ensure industry-ready graduates. In the UK GOV HE education and professional accredited bodies, it is required to embed graduate attributes into the engineering curriculum. Although the CDIO-based approach provides a platform where students can develop these skills, there is still a gap between students' skills and industry compatibility due to a lack of interaction with industry. Our solution is to embed industry outsourced CDIO projects in modules across the engineering course curriculum. These modules provide students not only the opportunity to develop their engineering technical skills but also their employability skills for actual industrial environment.

At our university, the academic team have adopted a robust 7-stage approach in consultation and collaboration with industry to identify and implement industry-sourced CDIO projects in the curriculum. Based on the nature and complexity of the project, the CDIO projects can be integrated into relevant modules at appropriate academic levels. For example, a design-related project can be integrated into the first-year module whereas complex projects are allocated to final-year students. The final objectives of the CDIO projects are aligned with the learning outcomes of the corresponding modules and should be reflected in the module assessments. In this paper, the approach and outcome of one of our industrial CDIO projects outsourced by eXroid (a biomedical company in the UK) have been described. During the period, students followed the four stages of CDIO framework. The performance of the students was satisfactory as 81% of the students passed the module on their first attempt and the average mark was 49.9. The feedback received from eXroid personnel and students regarding the project execution and outcome was outstanding. Students have also developed several industry-oriented technical and soft skills while executing the projects.

KEYWORDS

Graduate employability skills, CDIO project, Industry-oriented skills, Engineering curricula, Module mapping

INTRODUCTION

Students should be adaptive in this competitive world to become industry-ready graduates who can easily blend with the current job roles of the industry as proposed by professional accredited bodies (for example in the UK IET, IMechE) for higher education institutions. The top ten graduate employability skills (Atkinson & Bonfield, 2022; Engineering Council, 2020) sorted by large, medium and small enterprises are commercial awareness, communication, teamwork, negotiation and persuasion, problem-solving, leadership, organization, perseverance and motivation, ability to work under pressure and confidence (Archer & Davison, 2008; Jobs, 2019). To incorporate graduate employability skills in the engineering curriculum, integration of both technical skills and soft employability skills are necessary. After investigating the several pedagogic learning methods, the CDIO approach (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014) appears to be an effective way for implementing employability skills in STEM areas as it incorporates several pedagogical approaches together (Manna, S., Nortcliffe, & Sheikholeslami, 2020) such as problem-based learning (Savery, 2015), project-based learning (Pee & Leong, 2005), experimental learning (Tien, Namasivayam, & Ponniah, 2021) etc. However, there is still a gap between the engineering skill set and the expectations of the industry (Radermacher, Walia, & Knudson, 2014). If students do not have the opportunity to interact with industry, they would not understand the business perspectives, commercial viability and critical industrial standards of their developed project, and how to present the project in front industry panel. The integration of employability skills can be achieved through several methods (Arlett, Lamb, Dales, Willis, & Hurdle, 2010) including the use of industry-related problems in teaching and learning, relevant case studies, modifying curricula with the current industry trends, allocation of professional skills-building courses in the curriculum, workshops delivered by industry experts and career enterprise team and collaboration with industry.

Alongside traditional approaches such as problem-based learning (Savery, 2015) and project-based learning (Pee & Leong, 2005), several customized approaches have been incorporated such as Project Centered Curriculum (PCC) developed by the University of Queensland (Crosthwaite, Cameron, Lant, & Litster, 2006), industry-collaborated capstone projects as a community of practice (CoP) model developed by University of Liverpool (Topping & Murphy, 2022), open-ended major group based design projects by the University of Botswana (Moalosi, Oladiran, & Uziak, 2012) and Work-based learning model with partnerships considered by Politeknik Ungku Omar, Malaysia (Tuselim, Muhammad, & Mai, 2020). However, there is always a lack of direct involvement of industry, the opportunity to work under real-time industrial problems and customization of CDIO projects for specific levels of students.

To integrate engineering skill sets as per the industry expectations, we adapted industry outsourced CDIO projects through collaboration with industry partners. The CDIO framework emphasizes the integration of engineering theory and practice, and industry-outsourced projects provide students with the opportunity to apply their technical and employability skills and knowledge in real-world settings such as problem-solving, critical thinking, communication, teamwork etc (Archer & Davison, 2008). These skills are highly sought after by employers and are essential for graduates to be successful in their careers. Besides, industry partners can provide valuable input on the types of skills that graduates need to be successful in their careers and can assist in the design of projects that incorporate these skills. Collaboration with industry partners can also provide students with valuable networking opportunities and can increase the chances of students being employed by the collaborating company after graduation (Freitas, Marques, & e Silva, Evando Mirra de Paula, 2013). Existing research on the integration of graduate employability skills through industry-collaborated student projects has to be effective in preparing engineering graduates for successful careers (Podolskiy et al., 2018). A case study has highlighted the importance of careful curricular design in integrating employability skills through client-sponsored student projects (Bove & Davies, 2009). To integrate the benefits of the CDIO method and industry expertise, we collaborate with local small and medium-sized enterprises in the design and implementation of student-led CDIO projects. To execute the process efficiently, a novel and carefully designed approach is considered so that graduates who will participate in industry-outsourced CDIO projects tend to have better employment outcomes. A case study is discussed based on the above approach which is also proved to be effective and impactful in our curricula.

METHODOLOGY

In consultation and collaboration with the industry, a robust 7-stage approach (CAMIIRI model) is adopted to implement industry-sourced CDIO projects in the curriculum (Figure 1). The process consists of the collection of the CDIO projects, analysis of the depth and level of the projects, mapping the project objectives with the module learning outcomes, integration of the CDIO projects with specific modules, implementation of the four steps of the CDIO framework, reflection on the impact of the project outcomes, further improvement of the overall process.

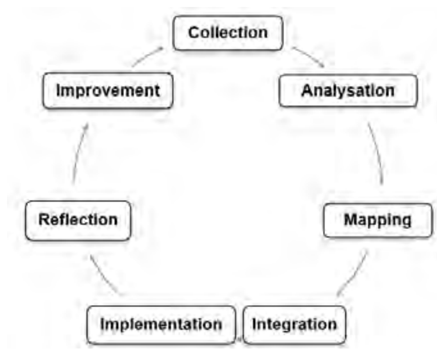

Figure 1. 7 Stage approach (CAMIIRI model)

First of all, we identify the feasible problems from the local industries through industrial visits, consulting with industry contacts, the university's industry liaison officer or the career and enterprise team.

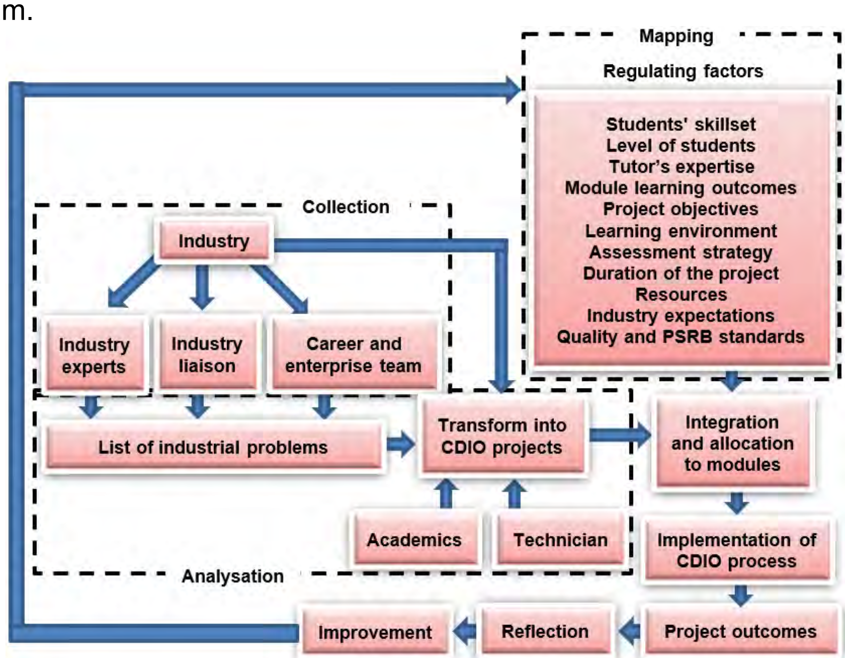

Figure 2. Implementation strategy of CDIO project

Only those industrial problems are usually considered if can be solved at the student level, no such research-intensive projects are not considered for CDIO projects. After that, those current industrial problems are transformed into potential CDIO projects in collaboration with relevant industry partners. The project transformation process is designed by keeping the students' mindset and their skillset in mind so that those projects can be achieved in the academic environment and the project's outcome should meet the required objectives of industry experts (Figure 2). Based on the nature and complexity of the projects, those projects are integrated into relevant modules and allocated to appropriate academic levels.

For example, an investigation-based research study or conceptual-model-based project is allocated for foundation year engineering students; a basic design-related project with a working prototype can be integrated into the first-year design module; a working prototype with a basic experimental study can be integrated with second-year module whereas high-tech and complex projects where commercial perspective is explored, hence would be allocated to final-year students. The process of integration is carried out very cautiously because there are several major factors involved in it such as students' skillset and levels, tutor’s and technicians' expertise, module learning outcomes, project objectives, learning environment, assessment strategy, industry expectations, Quality and PSRB standards, duration of the project and resources (Figure 3). It is important to map those regulating factors with module descriptors and CDIO project objectives so that specific CDIO projects can be allocated to appropriate modules. Students' skill sets of specific levels should align with the project's complexity so that it will be achievable within the timeline with adequate resources, usually within a semester. Sometimes one CDIO project is spread across two semesters based on the module descriptor. Also, the project should be completed by a group of students rather than individuals where each team member will contribute, exchange their ideas and support to achieve the final goal. The expertise of associated module tutors and technicians plays a major role in executing the project, for example, if the tutors cannot provide enough technical and professional support, it would not be beneficial for students to complete the project efficiently.

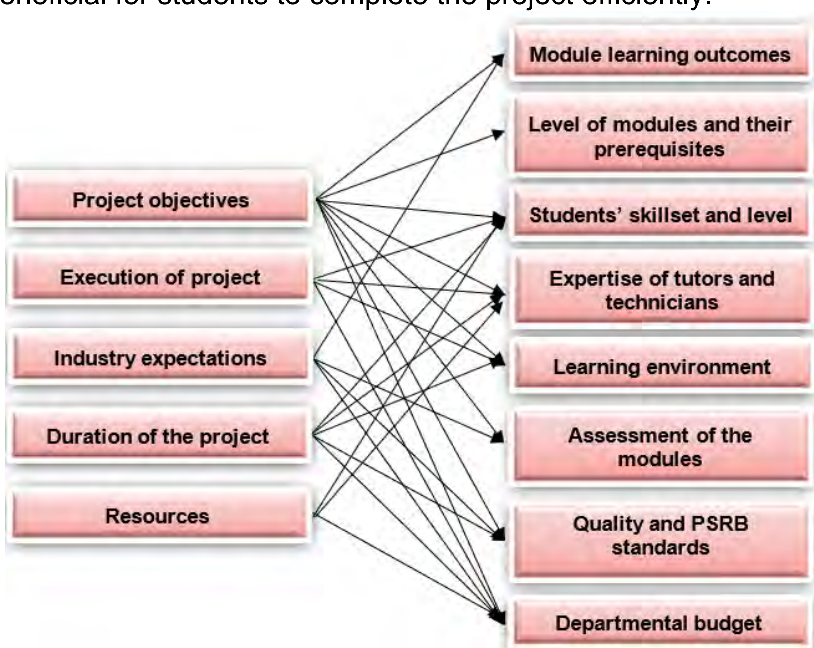

Figure 3. Mapping CDIO projects into a module

Alongside this, it would also need support from other co-tutors in case of more students. To maintain the quality of learning and teaching, we need to keep the staff and student ratio 20:1

at CCCU, hence there will be more tutors and technicians in the classroom for supporting a large number of students. The module learning outcomes and project objectives should be coherent. For integration purposes, the modules' learning outcomes are analysed in advance and only those CDIO projects are considered a part of the course if their objectives help to satisfy the module learning outcomes. There are some expected outcomes from the projects as suggested by industry experts, hence those expectations are usually conveyed to the students as their project objectives. The learning outcomes of the specific modules and the objectives of the CDIO projects are clearly defined to students with a clear focus with the aim to prevent project creep, however the key to prevent the latter is good academic support and team management (Anslow & Maurer, 2015). Therefore, the students were guided, managed and assessed by academic and industry experts. It is the responsibility of the module leader to design the learning environment for executing the CDIO project effectively. The learning sessions are divided into two sections: lectures (technical and professional) and practical sessions. Technical knowledge and professional skills are delivered by module tutors through lecture sessions which are beneficial for designing their projects and executing the project whereas practical sessions are dedicated to develop the final product. Our technicians usually help the students with technical support and resources. The learning sessions are arranged logically to facilitate the four stages of CDIO (Figure 4), for example, in the first two weeks, active learning session rooms are scheduled in the timetable so that students can complete the conceive part of the CDIO process through literature survey and brainstorming sessions in a group; for the next three weeks, the IT rooms are booked where students can design the 3D model and electronics design in simulation platform using several software; in the next three weeks, electromechanical lab, 3D printer and mechanical workshops are open for students to implement the project by developing the prototypes and electronics hardware circuit; in the last two weeks, the makerspace and mechanical testing labs are used by the students so that they can operate through experimental study for further improvements. All these sessions are supported by module tutors and technicians for technical or professional guidance.

CDIO stages	**Conceive**		**Design**			**Implement**			**Operate**			**Assessment support**
Week	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th	11th	12th
Sessions	Active learning lab		IT room (with relevant software)			3D printing lab, Electronics lab, Mechanical workshop			Makerspace, Material testing lab			Working on project reports and presentations
Student Activities	Understand the aims and objectives of the project Group work, Literature survey, brainstorming sessions to develop the concept.		Design 3D model, electronics circuit simulation/ mathematical models.			Develop mechanical prototype, electronic hardware. Implement programming if required.			Experiment to understand its working principle for further improvement			Review of individual technical/ business report Group Poster/ PPT presentation
Skills learned	Critical thinking Project investigation Communication Teamwork Project management Organisation Motivation		Technical skills (3D modelling, circuit design) Commercial awareness Negotiation Persuasion Problem- solving Leadership Teamwork Confidence Organisation			Technical skills (3D printing, circuit making) Problem-solving Ability to work under pressure Leadership Teamwork Organisation Hands-on skill			Critical thinking Teamwork Hands-on skill Organisation			Presentation Report writing Confidence Perseverance

Figure 4. Planned learning for CDIO projects

INTEGRATION OF GRADUATE EMPLOYABILITY SKILLS

Students will learn several technical and professional skills while pursuing the CDIO stages, for example, they can enhance their critical learning skills during the Conceive stage, problem-solving skills during the Design stage, and hands-on skills during the Implement and Operate stage. To adapt to the current HEI engineering framework, the course learning outcomes are validated based on Engineering Council AHEP 4.0 standards (Engineering Council, 2020). The technical and professional skills learnt during the CDIO projects can be mapped as fulling the graduate employability skillset as per the PSRB standards, and the project execution and outcomes are aligned with the university's quality framework. It is necessary to maintain the module credit, assessment policy, module learning outcomes, course contents, and contract hours for each module, hence the project objectives are nicely fitted into the module without overburdening the students. The required resources for the CDIO project are usually allocated from the departmental budget, something a few specific items are outsourced from the industry for experimental purposes. Maintaining affordability is always a challenge for CDIO projects, hence we always try to keep the overall budget within a limit so that it is feasible to finance. The students usually submit the list of resources, with their specifications, cost and links to the module leader. The list is reviewed by the module tutors and technicians. It is our recommendation to allocate in-house resources for the CDIO projects, otherwise purchased if required. Most of the time, students end up building a working prototype to provide the conceptual model rather than the actual commercial product due to the restriction of budget and prevent project creep as keeps tight focus, however, it still allows students to develop all these graduate skills set while developing the product.

Critical thinking is embedded into the process by promoting student-led and tutor-guided CDIO projects. Starting from the conceptual model, feasible solutions to the final prototypes are delivered by the students whereas tutors and technicians provide knowledge, technical and professional support whenever required. Hence it is possible to enhance the critical thinking and innovative mindset of students. Group work and team spirit are always nurtured through CDIO projects. To remove this conflict of engagement and to allow every group member to participate actively, the overall task of a project is allocated among the group members with sub-tasks and each member is assigned to fulfil the responsibility of the specific part of the project. All students are recommended to create a shared folder to share their individual progress with other team members. The advantage of such an approach is to ensure the team working is inclusive as it provides each student with the opportunity to develop their technical and employability skills. Despite the individual tasks in a group, students are still encouraged to support one another seeding teamwork skills. Besides, a certain percentage of the final assessment is kept as a peer assessment (Brown, 2015) where students will mark each other based on contribution and engagement in the project, hence each of the team members has the responsibility to drive the rest of the members to contribute to the project otherwise, the overall outcome would be degraded (Nortcliffe, 2012).

A discussion room was created on the blackboard module site to provide asynchronous support, and enabled students to share their weekly progress, doubts and receive academic feedback on areas to improve. Students from different courses such as mechanical, biomedical and product design engineering can participate to make a multidisciplinary project group, work together, share knowledge and innovate solutions. While developing the projects, students will also learn project management skills, leadership, organizational skills, communication with teammates and motivation to carry out the projects. They can learn and enhance several technical skills in software and simulation tools which will provide evidence for their CV for future job opportunities. Problem-solving skill is underpinned in each stage of the framework as the projects requires the students to work together to solve unknown engineering problems outsourced by industry whereas producing the product within the proposed deadline can improve their ability to work under pressure. The assessment strategy of the modules is one of the important factors. As the CDIO project is now an integral part of a module, its outcomes should be reflected in the module assessments as well. Based on the module validation document, group assessment (presentation/poster/report) or individual assessment (technical/business) are kept for formative/ summative assessment of a module. The aim of the module assessments was focused on empowering the presentation skill, report writing and confidence of students. Out of four assessments in the module, two assessments (group poster and individual technical report) are associated with the CDIO project. Another piece of assessment is reflective writing where students show their learning process throughout the project execution.

RESULTS

In this section, a case study on an industry outsourced CDIO project is discussed. In the last academic year, a CDIO project was outsourced by eXroid (a biomedical company in the UK) and executed during the second phase of COVID-19 restrictions, so an optimal arrangement of a blended learning approach (Manna, Soumya, Battikh, Nortcliffe, & Camm, 2022) was adopted. Lectures were delivered online whereas weekly practical sessions were arranged in person. The CDIO project aims are incorporated into the learning outcomes of a Level 4 mechatronics module and become a part of the summative assessments of the module. The communication between students and industry experts was arranged periodically over the semester. From time to time, students meet with the team of eXroid and received guidance from them, at the end presented in front of the academic and eXroid personnel. There were 38 students enrolled in the module. The innovative solutions developed by each group were brilliant and diverse (Figure 5).

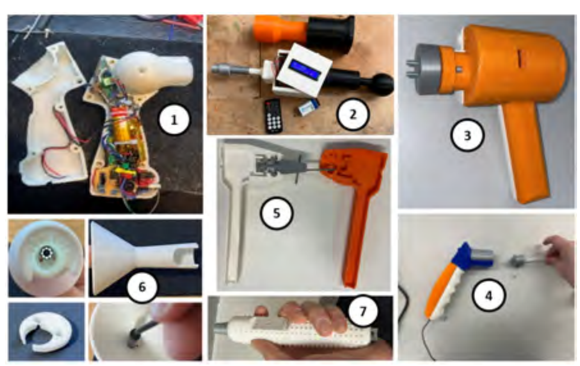

Figure 5. Prototypes of student-led solutions

Out of 38 enrolled students, 6 students did not engage effectively, either they drifted from the course or took studies interruption for a variety of reasons, but often health-related. The first-time overall pass rate was good (81%) and their average mark was 49.9 excluding zero and non-submissions and a standard deviation of 27.65. This module profile in terms of first-time pass rate was considered good, however the module learning has room for further development to improve the module class average. After evaluating students' data from student records, it was found that 100% of disabled students, 71% of female students, 40% of Black and Asian Minority Ethnic (BAME), 63% of low social, and 100 % of mature students passed the module on their first attempt. The quality of the artefacts as shown in Figure 5 was overall very good, the students lost grades through the quality of their project outcomes, report submissions and personal reflections. An NDA (non-disclosure agreement) was signed between the university and industry to preserve the development of the technology, also it will explore further opportunities for students such as internships, placement and jobs. The feedback received from eXroid regarding the project outcome was outstanding. Students also appreciated the overall learning approach, and they developed several technical and employability skills while interacting with the industry. Feedback from the students was collected for module evaluation. Attached please see a few quotes from eXroid personnel and students to show the impact.

Quotes from eXroid for several groups

“A progressive iteration on the existing device. Useful evolution of single-use probe design and like the shift in weight from the handle to box. “ – Group 3
“Innovatively diverse in concept to the other groups. The standing arm is a unique concept that we really appreciated, and the remote control concept and display were really great nuggets that hit the note for significant improvements for the practitioner.” – Group 5
“Really engaging presentation and the most holistic all round concept development. The rotational control; clamshell build change and connection breaking system showed real practical benefit for practitioner use, engineering production efficiency and security development.” – Group 6

Quotes from students from their reflection on CDIO projects

Student 1 - ‘While doing the CDIO project I’ve been able to improve upon my CAD (computer-aided design) skills. For these two subjects I've gained a lot of self confidence and the ability to speak with confidence during team presentations’.
Student 2 - ‘I feel that as a future professional engineer I have gained a lot of new skills as well as helped contribute to my team’.
Student 3 - ‘Working on a device with medical aspects was something. I believe the CDIO projects I've faced have pushed me to learn quickly and given me an excellent taste of what it's like to work for businesses. I've learnt a great deal about teamwork and how it can, with the proper structure and organization, lead to personal development and academic success.’

CONCLUSIONS

A well-designed curriculum can ensure that employability skills are integrated into the project in a way that is meaningful and effective. As engineering educators, it is important to ensure that employability skills are integrated into the curriculum to best prepare graduates for successful careers in the engineering field. The results from the case study and the feedback from students and industry personnel have shown that the industry outsourced CDIO project can be a path-breaking solution in engineering education as it can provide students with valuable opportunities to develop and apply employability skills in real-world settings. It is also reflected in their feedback that they enjoyed the learning process and enhanced their graduate attributes. Previously continuous support was provided online to disabled students in the form of additional accessible learning materials, and extra sessions so that they could catch up. This problem was partially resolved post-COVID as all sessions are now moved to face-to-face, hence in-person support was available to disabled students. This approach has been followed for the last three years and the current graduate students have received its benefits. Several students have received multiple graduate roles in different engineering sectors and others will pursue post-graduate education. After an in-depth investigation, it was found that the performance of BAME students was relatively poor (40%) compared to all cohorts, so additional training and support sessions have been arranged to close the BAME attainment gap, more inclusive methods of communication on how to foster BAME student engagement.

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FACILITATING STAFF IMPLEMENTATION OF TEAMWORK MEASUREMENT FOR ENGINEERING-RELATED PROJECT-BASED MODULES

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ABSTRACT

In Singapore Polytechnic, teamwork is valued as one of the graduate attributes expected of our students. Teamwork is an important part of the needed interpersonal skills to be developed and assessed as part of the learning outcomes of an engineering curriculum in part 3 of the CDIO (Conceive Design Implement Operate) syllabus. This paper shares the perspectives of teaching staff in implementing teamwork measurement for project-based modules in the School of Electrical and Electronic Engineering. All students will do at least one project-based module in Year 1 and Year 2 for their three-year-long diploma course of study. For the first time in the second semester of the academic year 2021/2022, teamwork measurement in self- and peer-assessment was implemented. In the next academic year, 40 teaching staff responsible for 68 classes of these project-based modules were involved in the first semester. For the second semester, 31 teaching staff, responsible for 52 classes, were involved. Survey findings gathered on staff perspectives in implementing teamwork through self and peer assessment, suggested that amongst others, staff supported its use to develop students' teamwork skills further as their students were able to gauge their own contributions, as well as those of their teammates. Staff also found it was easy to use for their classes, supported their observations of the students' teamwork skills and helped staff to identify the "free riders' in a team project. Overall, the findings will pave the way for improvements in the implementation so that both teaching staff and students are better prepared going forward, to meet the institutional requirement of teamwork measurement. The paper also shares the considerations and challenges faced for such a large-scale implementation.

KEYWORDS

Keywords: staff development, teamwork, project-based modules, CDIO Standards 2, 9

NOTE: Singapore Polytechnic uses the word "courses" to describe its education "programs". For example, a "course" in Diploma in Electrical and Electronic Engineering consists of many subjects termed as "modules"; which in the universities' contexts are often called "courses".

INTRODUCTION

Since the School of Electrical and Electronic Engineering (SEEE) of Singapore Polytechnic adopted CDIO as the engineering education framework for the delivery of its various diploma courses, it has over the years successfully implemented Standards 2, 4 , 5 and 8. Students are involved in experiential learning (Standard 8) when carrying out project-based modules, centred on introduction to engineering (Standard 4) and design-build experiences (Standard 5) to achieve the desired learning outcomes (Standards 2) (Chong, Chua, Teoh, & Chow, 2010) (Voon & Sale, 2009) (Pee, Leong, & Sale, 2009).

All Year 1 students, from its four diploma courses take up a common project-based module in their first year; Introduction to Engineering and Design. In Year 2, most students take up Microprocessor Applications as their project-based module, depending on their diploma course of studies. Aligned with the CDIO approach, interpersonal skills like teamwork, are done through the introduction and teaching of the skills. In the polytechnic, these are taught through institutional-wide modules in Year 1. These skills are put into practice by the students through the integrated learning experiences in the project-based modules offered by the school.

Singapore Polytechnic lists collaboration or teamwork, as one of the graduate attributes that it seeks to imbue in its students. In the academic year of 2020/2021, the polytechnic embarked on a pilot polytechnic-wide educational teamwork research project. The initial focus was on the systematic measurement of teamwork skills through self and peer assessment of its students. The project-based modules of the school provided a natural fit for this.

For the teaching staff, this represented a change in their usual practice of assessing the teamwork skills of their students. Typically, teaching staff use their own observations and interactions with the students while doing the group projects. They may gauge the teamwork skills from the contributions of individual students towards group project deliverables such as presentations, reports, and completed projects. With the additional aspect of self and peer assessment by the students, the teaching staff's assessment of the teamwork skills would be augmented by the input from the students themselves. This required the preparation of the teaching staff for its implementation (Standards 9).

This paper sought teaching staff's perspectives on using the instrument for teamwork measurement, and their experiences on the learning activity management system, on which teamwork measurement was carried out. To this end, a staff survey was conducted to gather their views. With these perspectives, the school aims to improve its implementation going forward to meet the institutional requirement to reflect students' teamwork skills.

LITERATURE REVIEW

Beyond acquiring technical knowledge and skills, the engineering graduate is also expected to possess teamwork skills. Most tasks in the engineering workplace are complex, and teamwork skills, amongst others, are needed for the engineering graduate to be able to perform and contribute effectively (Cerri, 2016). Teamwork skills thus become an important learning outcome of an engineering education and are included in part 3.1 of the CDIO Syllabus –Teamwork and Collaboration.

Appreciating the need for teamwork skills to be developed, engineering education programs seek to provide opportunities for students to work in teams. These include, through project work, team-based learning, and avenues for peer feedback amongst the students (Gibbard, et al., 2018). However, assessing an individual student's teamwork skills may not be so straightforward for teaching staff, for cases where the group project tasks take place outside the physical purview, of the teaching staff themselves.

An identified disadvantage of students working together on group projects is the possibility of "free riding" students, assessed to the same extent as the rest of the teammates, despite lacking the contribution to the team efforts. Understandably, not all students favour working in teams. Self and peer assessment that allow students to comment on their own efforts and those of their peers, could be used to minimise such incidences of free-riding, and to support the appropriate teamwork skills development of the engineering students. This can be done with relative ease of implementation for the teaching staff involved (Willey & Freeman, 2006). One other possible approach is to use web-based collaboration tools to capture students' off-class contributions and activities towards the team projects and these provide evidence of the teamwork skills of students (Lingard & Barkataki, 2011) (Beddoes, 2020). However, this could be more demanding on teaching staff in terms of having to go through this evidence.

A tool that has found use in teamwork measurement in engineering education is the Comprehensive Assessment of Team Member Effectiveness (CATME) (Ohland, Loughry, & Moore, 2007) (Chowdhury & Murzi, 2019) (Sripakagorn & Maneeratana, 2009), which incorporates assessing teamwork with self and peer assessment. Teamwork measurement has also been carried out in other schools within the polytechnic itself, centred on the students' perspectives (Soo-Ng & Tao, 2021), hence, the focus for this paper is on gathering the perspectives of teaching staff instead.

(For this paper, the terms "team' and "group" are used interchangeably, although the literature suggests distinctions such as common goals and task interdependence (Siha & Campbell, 2015), (Smith, 2014).)

IMPLEMENTATION AND APPROACH TAKEN

The school carried out teamwork measurement through self and peer assessment for the first time in the second semester of the academic year 2020/2021. In the first semester of the next academic year, 40 teaching staff were responsible for 68 classes for these project-based modules. In the second semester, 31 teaching staff, responsible for 52 classes, were involved. Given the considerable number of teaching staff involved, the school aims for a consistent implementation to simplify the tasks to be carried out by teaching staff who could be taking students from different diploma courses, even for the same project-based modules.

Instrument and Platform for Teamwork Measurement

As done in Singapore Polytechnic, the teamwork measurement instrument is adapted from CATME (Ohland, et al., 2012). For the self and peer evaluation, students are expected to report on the following five aspects on a 5-point Likert scale from 1 to 5, for themselves and their team members:

1. Contributing to the team's work
2. Interacting with teammates
3. Keeping the team on track
4. Expecting quality and
5. Having relevant knowledge, skills, and abilities

From the quantitative inputs, the Self and Peer Assessment (SPA) factor, and Self-Assessment to Peer Assessment (SAPA) factor are computed. The SPA factor shows how the individual student has performed relative to his teammates. A SPA factor of more than 1, indicates the student has done better than his peers. The SAPA factor is the ratio of the student's own rating as compared to his ratings by other teammates. A SAPA factor of more than 1 means that a student has rated himself higher than how the rest of the teammates have viewed him (Willey & Freeman, 2006).

In addition, each student also provides open-ended qualitative inputs on each individual teammate in two areas; firstly, on things that they appreciate of their teammates and secondly, on things that they hope their teammates can do better.

In Singapore Polytechnic, the Learning Activity Management Systems (LAMs) is the platform used for teaching staff and students to carry out the teamwork measurement. This is a separate platform from the learning management system (LMS), Brightspace, for the delivery of asynchronous learning contents in the polytechnic.

Considerations for the implementation of teamwork measurement

Two main factors of the project-based modules considered prior to the implementation of the teamwork measurement to assess their suitability are:

- Group projects contribute a significant percentage towards the overall assessment of the modules
- Number of students required to work in the groups for these modules

For the targeted project-based modules, the percentage weighting of the group project against the overall marks' ranges from 40% to 45%. The high weighting suggests task complexity of the group project requirements for these modules. To this end, teaching staff could find the teamwork measurement through self and peer assessment viable for implementation for their classes, as the SPA factor obtained can be used to moderate a part of the assessment to reflect the teamwork and the individual contributions of students.

Students typically work in groups of three to four, on the group projects for these project-based modules. Teaching staff typically have five groups per class and aim to have uniform student group size for fairness and equity in achieving learning goals and assessment. However, as actual class size may differ, if a larger group size is formed, teaching staff can set stretched project outcomes, for fairness in assessment.

The teamwork measurement ideally should be carried out twice, midway through the project undertaking, for formative assessment. This provides students the opportunity to improve for the rest of the project undertaking, and to motivate students further through affirming the individual student's positive contributions so far. The second measurement is carried out after completion of all group project deliverables, usually at the end of the semester. This serves as a summative assessment of students' teamwork skills.

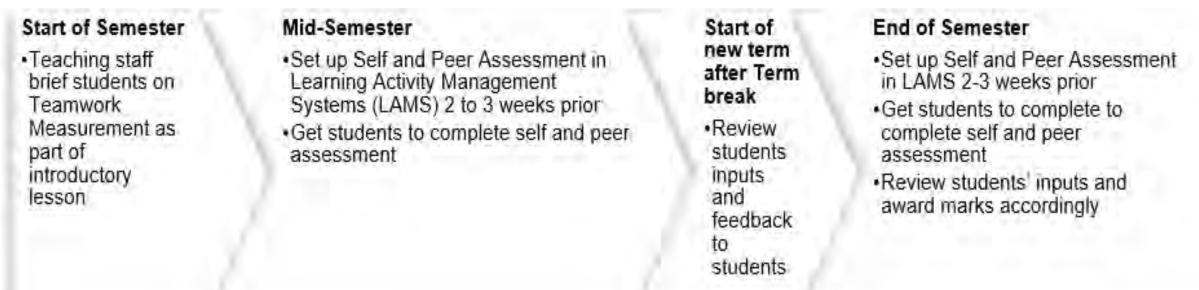

Figure 1 Timeline of Teamwork Measurement for Microprocessor Applications

Figure 1 shows the timeline for such an implementation for the Microprocessor Applications module. Teaching staff introduce teamwork measurements at the start of the semester. Prior to mid-semester, they carry out administrative tasks on setting up teamwork measurement for their classes and form groups in LAMs. Upon students' completion, staff can export the results in the form excel spreadsheets and use the computed SPA and SAPA factors and look up the qualitative feedback from the students. After the mid-semester before students resume on the group projects after the term break, they will need to follow up to share the feedback to their students' group if the teamwork assessment is used as part of formative assessment for students to improve. For summative measurement, teaching staff could use the results to moderate the individual marks through the SPA factor.

7Resources and Support for Teaching Staff Role in Teamwork Measurement

As with any change implementation, the teaching staff's concerns needed to be addressed. The extra administrative tasks required are to be seen against the possible advantages of having the additional insights that could be gained from self and peer assessment by the students. Apart from serving as an additional lens on students' teamwork skills, it helps to detect dysfunctional teams in the case of "free riders" and for staff to intervene as needed, and to moderate group marks to produce individual marks for assessment.

For teaching staff concerned with developing their students' teamwork skills, the teamwork measurement exercise helps students to develop and practise their judgement and evaluation of what makes good teamwork skills in scenarios that mimics the engineering workplace. Students are also given the chance to develop and exercise individual accountability.

Before the start of the semester, communication and briefing to all teaching staff involved was provided. Resources available for teaching staff's use included the following:

- Introductory slides on Teamwork Measurement for staff to brief their students
- Self and peer assessment statements and rubrics for staff to share with their students
- Step-by-step how-to-guides for teaching staff in both pdf form and video recordings on the use of LAMs, the use of SPA and SAPA factors and exporting results
- Frequently asked questions.

These were done so that the administrative and preparations tasks required of staff were as minimal as possible. In the initial stages of implementation, and for staff new to teamwork measurement, there was also support extended to help them set up the self and peer assessment activity within LAMS.

Beyond these administrative tasks, the real value that the teaching staff can bring is to facilitate honest and objective self and peer assessment by the students for the teamwork measurement. This will provide meaningful SPA and SAPA factors to help students in developing their teamwork skills further. Through doing these teamwork measurements more than once in different module settings guided by the teaching staff, students will hopefully appreciate aspects of teamwork skills to help them to become effective team contributors.

Flexibility of implementation

While the School aims for consistent implementation, in some respects, room must be made for flexibility in implementation. For some of the project-based modules, the group projects take place in the later part of the semester. For such cases, only summative teamwork measurements can be carried out, as within the relatively short time remaining for the rest of the semester, to carry out meaningful formative assessment of teamwork skills may not be feasible.
For forming groups within the classes, staff were encouraged to form mixed groups. For example, in terms of academic capabilities, teams can consist of students with a mixture of abilities, say high and medium capabilities, so that the groups are uniform in terms of overall capabilities (Francis, Allen, & Thomas, 2017). Students do also tend to form their own groups, preferring to team up with classmates they know and trust, based on experience. Some teaching members offer this autonomy to students.

The use of SPA is also strongly encouraged, though not mandated. For the SPA to be used, this depends on the extent of the objectiveness of the students in carrying out the peer and self-assessment, and the full completion by all students in the team. The SPA factor will not be valid otherwise, and staff can use the SPA factor where these two aspects are present.

RESULTS AND DISCUSSION OF STAFF SURVEY

Teaching staff who have taught the project-based modules and used the teamwork measurement (self and peer assessment) for at least one semester were sent email invitations to complete the survey voluntarily. The questionnaire is a quantitative part to gather staff's perspectives on various aspects of the teamwork measurement and one open-ended question.

Quantitative Results

Out of the more than 40 staff approached, 29 staff responded. Almost half or 48% have implemented teamwork measurement for one to two semesters, 13 staff or 45% of them for three to four semesters, and two staff or 7% have implemented for more than four semesters.

Figure 2 shows the survey results to gather staff's perspectives on various aspects of the teamwork measurement. For each of these, the responses required were on a 5-point Likert scale. For simplicity, responses for strongly agreed and agreed were combined, and similarly those for disagreed and strongly disagreed, while neutral responses were left intact. Overall, for all aspects, the percentages of staff who strongly agreed or agreed ranges from a high of 86% to the lowest of 52%.

A high percentage of 86% strongly agreed/agreed, on the following factors:

i) Ease of setting up the self and peer assessment lesson on LAMs
ii) Staff know how to interpret the self and peer evaluation results
iii) That teamwork measurement was useful for students to give feedback on teammates on their contribution to the project and
iv) That teamwork measurement was useful for students to evaluate themselves on their own contribution.

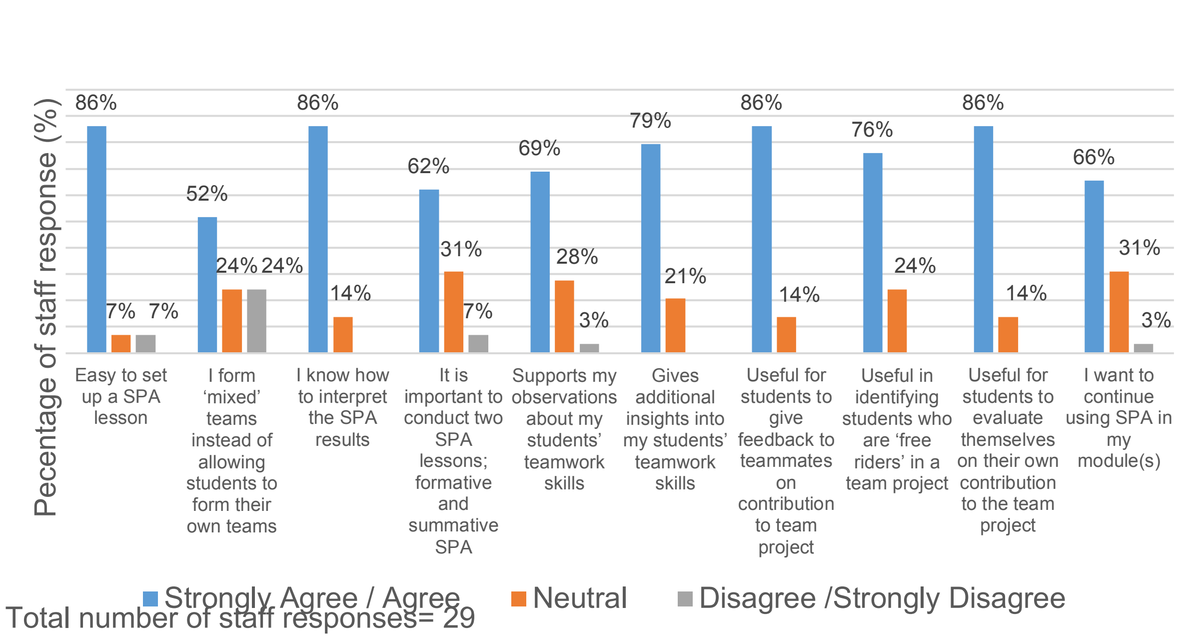

Figure 2. Staff response on the use of Self and Peer Assessment for Teamwork Measurement for project-based modules on various aspects

Similarly high percentages of 79% and 76% of staff strongly agreed/agreed that the teamwork measurement provides additional insights into their students' teamwork skills and is useful to identify "free riders" in the project groups, respectively. Slightly lower percentages of 69% and 66% of staff strongly agreed/agreed to the statement that it supports their observations about their students' teamwork skills, and that they will continue to use self and peer assessment in their modules if available, respectively.

A lower percentage of 62% of staff strongly agreed /agreed that it is important to have two teamwork measurement points, formative and summative. The lowest percentage of 52% of staff who strongly agreed/agreed, was obtained for the formation of "mixed" groups. This suggests that the teaching staff value "mixed" teams and took the extra effort to form such groups, though this formation of mixed groups was not mandated.

Qualitative Results

This section discusses the responses received to the open-ended question of "Additional useful feedback I have on the use of Self and Peer Assessment". The viable use of teamwork measurement through self and peer assessment is supported through statements like

- "*useful tool*" and
- "*Good tool to assess the team projects*".

However, staff's statements such as

- "*could only be useful if students give sincere feedbacks*",
- "*Insights more significant in groups with free riders*",
- "*If members are not prepared to be honest in their feedback, then it will be difficult to meet the objectives of using it*",
- "*Students always give the highest marks to each other*", and
- "*The usefulness of this tool depends on the truthfulness of assessment given by students to their peers",*

Suggest the need that the students could be more conscientious and objective in completing the self and peer assessment. This calls for teaching staff themselves to actively facilitate the exercise, spelling out these aspects to the students. They could caution students not to beat the system, as free riders could be called out based on much higher SAPA factors, while high ratings for team members must be supported by corresponding evidence in the qualitative part of the teamwork measurement.

The need for the teaching staff to actively facilitate the actual teamwork exercise is further inferred through statements like

- "*Some students not really spend much time to complete the Peer Assessment i.e., completed in less than 1 minute*", and
- "*Only very few students write comments. Others write NIL or leave blanks which defeats the purpose*".

Staff may need to provide students with the time and space within the scheduled lesson so that students can carry out meaningful self and peer assessment.

Despite the availability of resources on the use of the SPA factor and how-to-guides to download the results, statements such as

- "*Some difficulties understanding the downloaded results initially when I started to use SPA for my modules. Would be good if there is a guide to explain the downloaded results*" and
- "*Staff need to understand the SPA*".

suggests that staff may need easy access to refer to the resources provided. A central prominent one-stop resource may be needed as currently the resource is a shared link provided to staff, and more detailed slides for staff's reference.

There is a suggestion to

- "*Just use Brightspace for all teaching and assessment matters*".

This points to the use of the polytechnic's learning management system (LMS) as a platform for teamwork measurement. Unfortunately, the current LMS does not lend itself as a viable platform for the purpose. A link to LAMS can be provided in the LMS for each project-based module site, if this is not already provided. Similarly, a link to a future one-stop resource can be provided in the LMS for the teaching staff.

In a similar vein, suggestions for improvements to the current implementation include

- "*More friendly form or interface for students to enter their reflection and for staff to provide feedback*" and
- "*Need for breakdown of the tasks associated with formative and submitted assessment test so that students are clear on what they need to provide in terms of feedback for the open- ended qualitative inputs".*

The first part of the first suggestion may not be so viable as the LAMs platform itself may not be so easily modified to meet the suggestion. Instead, a self-access video can be provided to students themselves or for staff to share this with students. Feedback from the staff themselves to students in person is better than through the LAMS interface, even if this is possible, as this allows for easier clarification.

The second suggestion may be better taken up by the respective project-based modules' subject matter experts and teaching members themselves. Together they can draw up a viable list of tasks expected of students while working in the group projects. This list can be shared with students at the outset, in terms of the expected end-products (whether proposals, presentations, or working projects) and the processes to achieve these in terms of teamwork behaviours and activities (Marin-Garcia & Lloret, 2008).

There is one suggestion on "*marks awarded for teamwork should remain low as it is not a fair judgement of students' willingness to work in teams the reason being that some students tend to do more than others* ". This suggests the need for task complexity of the group project requirements to be re-examined and could be made more substantial, rather than the teamwork measurement itself being wanting.

Another feedback is that having to conduct both formative and summative teamwork measurements pose time constraints, a possible contributing factor for the earlier result of only 62% of staff strongly agreed /agreed on two teamwork measurement points, formative and summative. Apart from making the implementation as easy as possible for the teaching staff and for students, there is already provision in place that when the group project work happens in the latter half of the semester, then summative teamwork measurement suffices. Another suggestion is to enable the teaching staff to reject student inputs and asked them to redo if they did not complete the assessment well. While this feature can be made available, it is better if the teaching staff could guide their students to get these "right" the first time and makes further the case that the teaching staff facilitate the students actively during the process.

Limitations of the survey

The survey did not make any specific attempt to further breakdown the results in terms of the diploma course taught by the staff as the teaching staff could be assigned to teach students from different diploma courses for the same project-based modules. Also, the survey did not seek the teaching staff's views on how they perceived their role in developing students' teamwork skills, beyond administering and facilitating the self and peer assessment for teamwork measurement, as this is expected of them in their role as teaching staff.

CONCLUSION

The use of teamwork measurements for assessing teamwork for the project-based modules for first year and second year students administered by the teaching staff in the School of Electrical and Electronic Engineering has overall received positive responses. Teaching staff found it is easy to do the required tasks on LAMs and the students' inputs support their own observations of their students in terms of the students' teamwork skills.

The degree of usefulness, however, require the active facilitation of the teaching staff to guide and remind students on the need for conscientious and objective inputs so that the feedback gathered will be of use to benefit students' further development of teamwork skills. This is also to reflect the true extent of the individual contribution to the group project for assessment moderation.

Easy availability of resources, including access to a one-stop resource that the teaching staff can use to guide their students to carry out meaningful teamwork measurement exercise can help to further improve the implementation. On the curriculum side, the project requirements may need to be re-examined to ensure the group project demands, and the associated learning activities can both justify and guide students on essential teamwork aspects of group projects for the project-based modules. Teaching members of the project-based modules could be brought together in a workshop-style arrangement so that these could be explored further. Such sessions can also be conducted to seek their views on what they themselves have done, and what could have been done better to facilitate their students to carry out the self and peer assessment teamwork exercise meaningfully (Matsusovich, Paretti, Motto, & Cross, 2012).

The use of teamwork measurement through facilitation of teamwork skills of students by teaching staff in carrying out group projects and assessment by rewarding individual contributions can pave the way for development of student teamwork skills, needed for the actual engineering workplace.

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CASE STUDIES OF INTEGRATING PROJECT BASED LEARNING INTO POLYTECHNIC ENGINEERING CURRICULUM

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ABSTRACT

Project-based learning provides opportunities for learners to apply knowledge and skills that they have learned to answer driving question(s) based on authentic problems or projects provided by the industry partners. Literature has shown that project-based learning develops learners to be better problem solvers and high-order thinkers, as well as improves learners' engagement. Hence, project-based learning has been adopted by School of Engineering (SEG), Nanyang Polytechnic (NYP), Singapore as one of the teaching methods to further improve the learner and teacher engagement, develop learners' critical core skills and close the learners' achievement gap. This paper details the journey of integrating project-based learning into the curriculum of three diplomas in SEG after a successful pilot study on adopting the Gold Standard project-based learning model provided by PBLWorks (Buck Institute for Education). Implementation in each diploma was uniquely designed to suit the curriculum and the needs of the learners. The modules adopting project-based learning teaching method required learners to apply knowledge and skills learned at different stages to answer driving question(s) based on authentic problems or projects provided by the industry partners. The effectiveness of project-based learning implementation was measured through the perceptions of the learners and feedback provided by both learners and lecturers. The learners showed interest in the projects and found them useful in developing the competencies necessary for the diploma. The paper will also share the challenges faced during the implementation and discuss the possible improvements that can be made to enhance future implementation.

KEYWORDS

Project-based Learning, Curriculum Design, CDIO Standard 7 Integrated Learning Experiences, CDIO Standard 8 Active Learning

INTRODUCTION

One of the main roles of engineers is to solve technical problems using their mathematical and science skills and competencies. Often, these problems will translate into projects of varied complexity. For the projects to be successful, future engineers should also be equipped with the necessary 21st century skills and be resourceful. Therefore, project-based learning is adopted by School of Engineering (SEG), Nanyang Polytechnic (NYP), Singapore, as one of the teaching methods, to equip learners with the necessary skills and competencies as future engineers. Studies have claimed that project-based learning provides several positive learning outcomes for learners, such as the development of problem solving and high order thinking skills (Pinho-Lopes & Macedo, 2014), better learning attitudes and “comparable or better” performance on content knowledge (Parker et al., 2011), and improved learner engagement (Almulla, 2020).

In SEG, from 2019 onwards, we contextualized and integrated the Gold Standard project design elements, teaching practices and lesson delivery phases developed by Buck Institute into the project modules, as well as the new techniques and tools that are developed for lecturers who are involved in delivering the project modules (Wong et al., 2022). After a successful pilot study in 2021, this paper describes the journey of integrating project-based learning into the curriculum of three diplomas in SEG, namely, Diploma in Nanotechnology & Material Sciences (DNMS), Diploma in Engineering with Business (DEB), and Diploma in Advanced & Digital Engineering (DADM). Implementation in each diploma largely followed the contextualized methodology described by Wong et al. but was uniquely designed to suit the curriculum and the needs of the learners.

METHODOLOGY

The three diplomas followed the four delivery phases, namely *Launch*, *Build*, *Develop* and *Present* phase (Larmer, Mergendoller & Boss, 2015, Wong et al., 2022) for their project-based learning implementation. It draws similarity with CDIO where Conceive, Design, Implement and Operate can be matched to the 4 delivery phases (Launch, Build, Develop, and Present) of project based learning Each phase consists of a whole suite of recommended activities to be done to achieve the desired outcomes. Figure 1 shows a typical thirty to ninety hours project module in SEG and how the project design elements, teaching practices and learning activities are integrated into a project-based learning module over a period of 15 weeks. Contextualization effort here would mean selecting an adequate amount of important and yet manageable activities to be carried out in each project lesson delivery phase to achieve the outcomes.

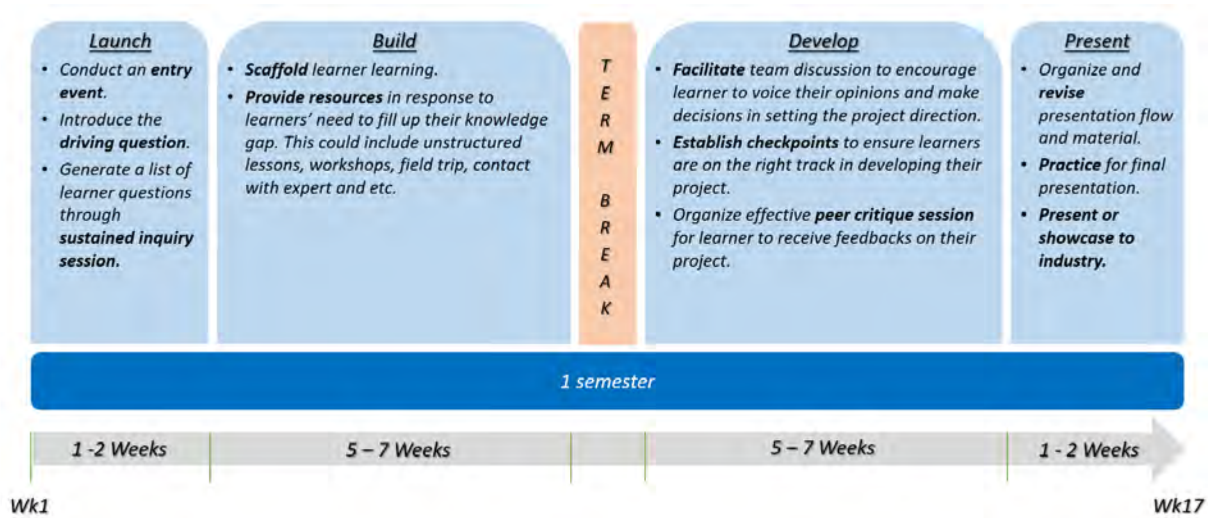


Figure 1: Project-based Learning Lesson Delivery Phases

For the Launch phase, entry event, introduction of driving questions and sustained inquiry session are the 3 activities to be carried out within the first 2 weeks for learners to get into the mood of starting their projects and to answer driving question(s) based on authentic problems or projects provided by the industry partners.

For the Build phase, a duration of five to seven weeks is recommended for learners to build up their knowledge and skills that are required for their projects. Structured or unstructured lesson can be conducted to scaffold learners learning. Activities such as field trip, workshop, talk by expert were recommended to be put in place as well.

After two weeks term break, the learners will proceed to the Develop phase to start developing their projects and a duration of five to seven weeks is recommended for learners to complete their project. In this phase, lecturers facilitate learners' team discussion, establish checkpoints to ensure learners are on the right track in developing their projects. An effective peer critique session should be organized for learners to receive feedback for their projects for further improvement or revision.

The last Present phase, learners are given one to two weeks to prepare and design their slides for their public presentation. Lecturers will review their slides and conduct practise sessions before the final presentation to the public.

IMPLEMENTATION

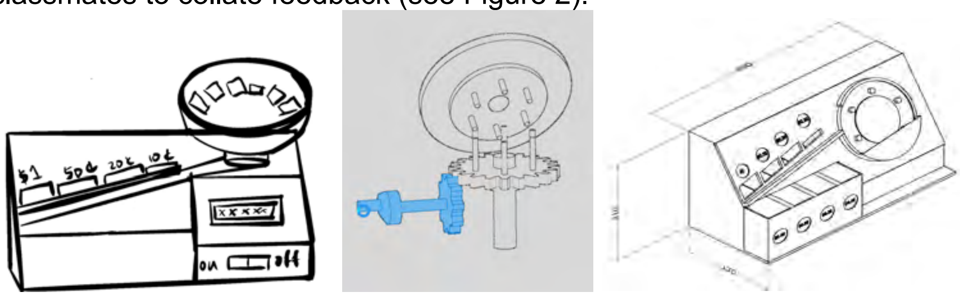
The project-based learning methodology was adopted by the three diplomas, for a total of three semesters from Year 2 Semester 1 to Year 3 Semester 1. The following subsections provide details on the implementation of each of the three diplomas following the four Project-based Learning Lesson Delivery Phases.

Diploma in Advanced & Digital Manufacturing (DADM)

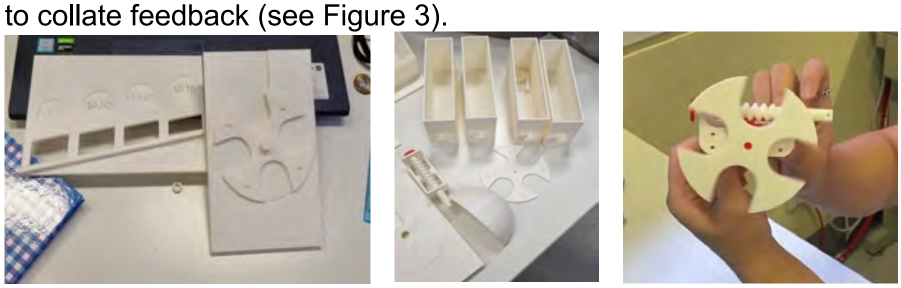
The curriculum of DADM was designed to prepare learners on precision engineering with Industry 4.0 and how it can be applied to every stage of product development – from design and creation, to tool and component manufacturing. The projects conducted in DADM were done progressively and sequentially in 3 modules, namely Integrated Development Project (IDP) 1, 2, and 3, with a possible progression to Internship or Final Year Project, which is done in the final semester of the course of study. Each of the module has a 60-hour class contact time.

(a) Integrated Development Project 1

Phase	Summary of activities
Launch	To interest the learners on their driving question, the learners were asked to solve a problem by playing a mini game. After the game, the driving question was provided to the students. Driving question was "How do we ensure precision in daily activities?". Project guidelines and limitations, such as (1) product must include at least 1 material from each of the following 3 groups: non-ferrous metal, ferrous metal, and polymers, (2) must include at least 2 mechanical elements and (3) using at least 3 different manufacturing methods.
Build	Topics such as Project Scheduling and Resource Management, and Advanced Manufacturing Technology (such as manufacturing of components using machining technology and numerical control in machining technology) were taught to equip learners with the necessary skills for the project.

Develop	The facilitator provides guidance to the learners to complete the deliverables needed, based on the guidelines and limitation provided in the Launch phase. This includes Low Fidelity Prototype, Project Initial Plan, Current Status of Project and Planned Status for IDP 2, and Logbook.
Present	The learners share their low fidelity prototype drawings to the facilitator and classmates to collate feedback (see Figure 2).  Figure 2: Examples of low fidelity prototype drawings

(b) Integrated Development Project 2

Phase	**Summary of activities**
Launch	The driving question on "How do we ensure precision in daily activities?" is revisited, and each team does a short presentation of their solution design from the previous module. The guidelines, limitations and deliverables were discussed.
Build	Topics such as Project Risk Management and Reporting, and Manufacturing of components using advanced machining technology were taught to equip learners with the necessary skills for the project.
Develop	The facilitator provides guidance to the learners to complete the deliverables which includes High Fidelity Prototype, Project Statue Report, Current Status of Project and Planned Status for IDP 3, Logbook and a Project File.
Present	The learners share their high-fidelity prototypes to the facilitator and classmates to collate feedback (see Figure 3).  Figure 3: High-fidelity Prototypes produced from IDP 2

(c) Integrated Development Project 3

Phase	**Summary of activities**
Launch	The driving question on "How do we ensure precision in daily activities?" is revisited, and each team did a recap on their project status in IDP 2. The guidelines, limitations and deliverables were discussed.
Build	Topics such as Introduction to Industry 4.0, Data Visualisation, UX for IoT, Marketing Survey and Project Pitching were taught to equip learners with the necessary skills for the project.

Develop	The facilitator provides guidance to the learners to complete the project with a working prototype incorporated with IoT.
Present	The deliverables include a poster and a working prototype (see Figure 4).  Figure 4: Example of a poster and a working prototype for IDP 3.

Diploma in Engineering with Business (DEB)

The curriculum of DEB was designed to merge the engineering and business disciplines, with the intention to equip the students with 21st Century skills to solve complex problems in the technically oriented business workplace. Under the project-based learning method, a series of three modules: Integrated Project – Ideation, Integrated Project – Realisation, and Integrated Project – Entrepreneurship, were developed and implemented as an essential part of the DEB curriculum. Each of the module has a 30-hour class contact time.

(a) Integrated Project – Ideation

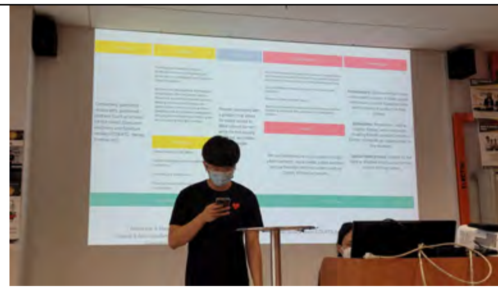
Phase	**Summary of activities**
Launch	The problem statements of the project are sourced from our industry partners or community collaborators, and they are presented to the students at the start of the module.
Build	To equip the students with the tools needed in developing solutions to the problem statements, human-centred design (HCD) approaches, which include Design Thinking, User Experience Design and Universal Design, are introduced.
Develop	Using the HCD approaches, the students are guided and facilitated to design and develop solutions to the problems. At this stage, they will create mock-ups or poster to explain their designs.
Present	During the final presentation, representatives from industry partners or collaborators are invited as members of the assessment panel. The learners present their solutions and receive feedbacks from the panel so that they can further improve their designs, as shown in Figure 5.  Figure 5: Learners presenting their solution design

(b) Integrated Project – Realisation

Phase	Summary of activities
Launch	The problem statements are revisited, and each team does a short presentation of their solution design from the previous module. The facilitator conducts a briefing on the tools and equipment available at the school's MakerSpace.
Build	The learners build their prototypes at the MakerSpace, as shown in Figure 6, through applying the knowledge and competencies in mechanical design, electronics and software attained from modules in the course.  Figure 6: Learners building their prototypes in the school's MakerSpace.
Develop	The facilitator guides the learners through an iterative process of testing, evaluation and refining of the prototypes.
Present	During the final presentation, whenever feasible, the representatives from industry partners or collaborators are again invited as members of the assessment panel. At this stage, some projects are identified to have potential to further develop into a full product and will be followed up as a 3-months long Final Year Project, which is part of the course curriculum.

(c) Integrated Project – Entrepreneurship

Phase	Summary of activities
Launch	At this stage, all teams are presumed to have a working prototype for their product. Each team does a short demonstration of their prototypes from the previous module. The facilitator presents to the students on the purpose of the module which is to develop a business model and write a business proposal based on their product.
Build	The facilitator presents the concept, principles, and process of setting up business as an entrepreneur. Tools like Business Model Canvas are introduced.
Develop	Using the knowledge and competencies they have acquired from the business-related modules in the course, together with the newly introduced tools, the students develop a complete business model of their product, which includes value proposition, customer segmentation, market analysis, cost analysis, etc. A business proposal is also drafted at this phase.
Present	During the final presentation, the assessment panel acts as potential investors, and the students pitch their business models and demonstrate their products.

	 Figure 7: Learner pitching their business model during the final presentation.

Diploma in Nanotechnology & Materials Science (DNMS)

The curriculum of DNMS was designed to equip learners with the necessary skillsets in meeting the emerging needs of materials and nanotechnology in various sectors. Like the other two diplomas, there were three modules identified to roll out project-based learning, namely Foundational Materials Science and Application, Polymers and Composites, and Materials Processing and Integration. Each of the module have a 90-hour class time, with at least 45 hours allocated for project. However, each project conducted in DNMS were independent of the other project. For each project, at least 2 technical core modules were designed to support technical knowledge required in the project.

(a) Foundational Materials Science and Application

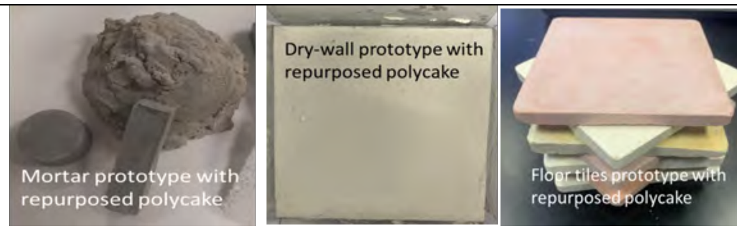
Phase	Summary of activities
Launch	Entry event was organized at the beginning, with the industry collaborator invited to give a talk on the project. The driving question "How can we improve the corrosion resistance of steel products to reduce impact and save cost for industry?" was shared to the learners in the event.
Build	The facilitator equipped learners with the necessary knowledge in the field of steel products and provided guidance to learners in planning their experiment to address the driving question.
Develop	The facilitator provides research and testing support for students to investigate. The industrial collaborator provided samples for learners to experiment, test and characterize their results. Figure 8 shows an example of the steel sample and experiment setup, as well as learners in action during their experiments.  (i) (ii) (iii) Figure 8: (i) An example of the steel sample, (ii) example of an experiment setup, and (iii) learners in action during their experiments.
Present	The learners prepared a report to document the experiments done and the results. Also, the learners presented their findings and recommendations to the industry partners, facilitator, and their classmates.

(b) Polymers and Composites

Phase	Summary of activities
Launch	The collaborator was invited to give a talk on the project, to highlight the relevancy of their project to the industry application. The driving question “How can we develop an environmentally friendly composite for sound absorption application?” was introduced to the learners.
Build	Facilitator taught learners on composites, their properties and processing techniques. Learners were provided with budget to source for their own materials. The school provides the necessary lab facilities for materials processing, testing, and prototyping.
Develop	The instructor provided guidance and supervision through sustain enquiry activity and processing and testing equipment training. The collaborator provided expertise and advised to the students on the applications and implementation of the composites. An example of the composite produced by the learners, and the impedance tube to test the performance is as shown in Figure 9.  (i) (ii) Figure 9: (i) a composite sampled produced by learners and (ii) impedance tube.
Present	A public showcase was arranged, to allow learners to have an opportunity to share with industry partner their project work/learning and seek feedback to improve their work.

(c) Materials Processing and Application

Phase	Summary of activities
Launch	The collaborator was invited to give a talk on the project, to highlight the relevancy of their project to the industry application. The driving question “How can we develop alternative applications of the Acrylic Polycake industrial waste materials to contributes towards sustainability and economic benefits?” was introduced to the learners and they are able to clarify their doubts directly with the collaborator during the talk.
Build	The facilitator explored on the waste materials composition with the learners. The processing and testing methods were introduced. The facilitator guided the learners to plan their project schedule.
Develop	The collaborator provided the industrial acrylic polycake waste while the facilitator provided consumables, as well as lab facilities for materials processing, testing, and prototyping. Collaborator provided mentorship to the learners while the facilitator provided guidance through sustain enquiry activity and process and testing equipment training.
Present	The learners presented their prototypes and project finding to the collaborator and facilitator at the end of the project. Some of their prototypes can be seen in Figure 10.

	 Figure 10: Prototypes produced at the end of the project

EVALUATION METHODS

To evaluate the effectiveness of the project-based learning method to our learners, 2 methods were used. The MUSIC Model of Motivation (Jones, 2009 & 2018) was adopted as part of the survey instrument to measure the impact of project-based learning on learners' motivation in five dimensions, namely empowerment, usefulness, success, interest and caring. An additional dimension on soft skill is added into the survey instrument (Wong et al., 2022). From the response to the questionnaires, a score was obtained for each scale, by calculating the average of the values for the questions in the scales, as recommended by Jones (2018) in the MUSIC Model of Motivation. This evaluation method was adopted by DADM and DNMS.

The other evaluation method was a combination of a survey with 18 statements and a focus group discussion (FGD). The survey's statements adopted the 3M – Meaningful, Motivational and Memorable (Bretz, 2001, Harackiewicz et al., 2002, Zubairu, 2016) to understand the learners experiences. The survey questions together with the classification of their categories, and the related learning experience using 3M can be seen in Appendix I. From the survey results, four statements with the lowest response scores were identified and used as discussion points in FGD. The FGD involved 8 learners from different levels and classes and were facilitated by 3 facilitators. This method was used to evaluate the DEB projects.

FINDINGS AND DISCUSSION

Adaptation from MUSIC Model of Motivation

The survey was rolled out to the DADM and DNMS learners at the end of the module. The learners were encouraged to respond to the survey; however, it was kept optional to receive genuine responses. All responses were tabulated, and a score was obtained for each scale, by calculating the average of the values for the questions in the scales, as recommended by Jones (2018) in the MUSIC Model of Motivation. The results were placed in a bar chart and was compared with the target score of 5.0, while the maximum score is 6.0. An example of the results for a module is shown in Figure 11.

In the survey, learners can also provide written feedback to the facilitators. With the scores and learners' feedback, the team discussed with the module leaders on possible contributing factors for lower scoring and areas for improvement.

The results from the surveys done across the modules found that learners felt cared for (caring) as facilitators do their best to scaffold the learning, and they were given ample of opportunities to practice their soft skills (soft skills). Learners also felt empowered (empowerment) as they were given autonomy to design their prototypes or experiments within the guidelines given.

Learners were interested in the project (interest) and found the project to be useful for their learning (usefulness), so long as they saw relevancy in the project.

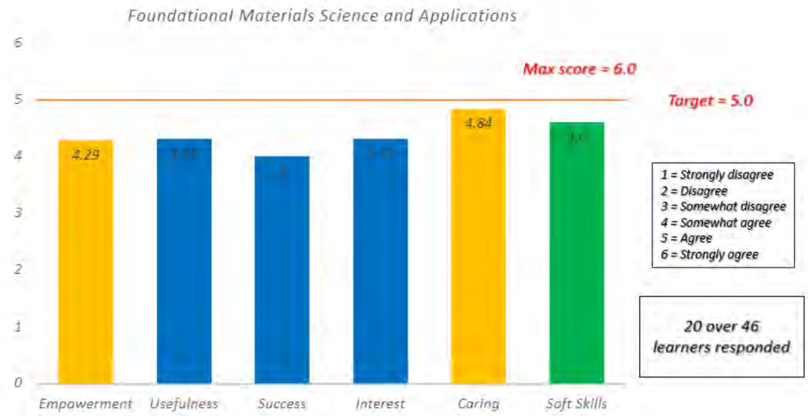


Figure 11: Results from the MUSIC Model of Motivation survey for DNMS's Foundational Materials Science and Application module

However, learners felt less confident in their abilities to complete their projects (success). Learners cited insufficient preparatory lesson and resources to prepare them for the project, and at times, unclear module delivery, project and assessment components that were communicated to them. For improvement, module leaders will work on better communications to the learners on the intent, limitation, and assessment components of the project. Module leaders were also encouraged to conduct peer evaluation periodically, as some learners shared unhappiness in workload among teammates, which could undermine their success in completing the project and scoring a good grade. Peer evaluation will be able to assist facilitator in mediating the issue quickly.

3M Survey with FGD

The 3M survey in Appendix 1 was rolled out to the DEB learners at the end of the module. All responses were tabulated, and a score was obtained for each statement category. A Likert scale of 10 was used, with a score of 1 given for strongly disagree while a score of 10 for strongly agree. Table 1 shows the mean score received.

Statement Category		Mean score
1	Team Dynamics	8.04
2	Self-fulfilment	7.50
3	Applicability	7.48
4	Skills	7.38
5	Assessments	7.08

Table 1: Mean score for each Statement Category for the 3M Survey with DEB learners

All five categories (Team Dynamics, Self-fulfilment, Applicability, Skills, and Assessments) have a high score of higher than 7.0. The high scores of the responses provided a reassurance to the facilitators that the delivery of the modules was in a good shape. It also showed that, in general, the learners were motivated, they found the modules meaningful, and their experiences in attending the modules were memorable.

Team Dynamics has the highest score, and Assessments has the lowest. The learners' experiences were very much influenced by their relationships with teammates. With a high score in Team Dynamics, we are confident that the current management of the team dynamics during the lessons is effective. The low score in the category of Assessments reflected the frustrations some learners have where they feedback that the effort that they must put in is too much for a 30-hour module.

Four questions with the lowest scores were further discussed in depth in FGD. Some insights into important operational issues were gained from the learners' perspective. First, a peer assessment is recommended to avoid the perception of unfairness where some team members put in less effort than others and the facilitator is unaware of it. Second, there were too many different microcontroller platforms available as choice and the learners find it confusing when developing the prototype. It is recommended to standardize on one microcontroller platform. Lastly, there were too many assessment tasks in the modules and hence a review of the number of assessment tasks is recommended.

CONCLUSION AND REFLECTION

Three diplomas in SEG have successfully implemented project-based learning with the four delivery phases, namely *Launch*, *Build*, *Develop* and *Present* phase. Even though there were slight variations among the implementations, similar findings were observed between both surveys. The learners were interested in the projects and found them useful in developing the competencies necessary for the course. Across all projects, the learners' confidence score in completing their projects seem lower, and assessments are often a main concern for the learners as this concerns their grades. This would require an in-depth study to explore how and why project-based learning appears not able to increase learners' confidence in completing the project.

With the successful roll out of project-based learning in these diplomas and the relevancy to the learners, the team is looking into assisting more diplomas to adopt the method. The team will also plan to provide more structured training to support module leaders in integrating project-based learning into the project modules, as well as equipping them with the facilitation skills which are essentials in delivering project-based learning lessons.

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APPENDIX I

S/No	Survey items about your experience in attending Integrated Project (IP) modules: After attending Integrated Project modules, I …	Category	Meaningful Motivational Memorable
1	feel closer to my teammates than before.	Team Dynamics	Mem, Mot
2	am satisfied with the way teams were formed.		Mot
3	become a better team player than before.		Mot, Mean
4	find it enjoyable to work on the projects with my teammates.		Mem, Mot
5	have gained skills in handling machines and equipment when making the prototypes.	Skills	Mot
6	have gained skills in programming and using CAD software.		Mot
7	am confident to apply the skills (both in hardware and software) I acquired in the future.		Mot, Mean
8	find it enjoyable to learn how to use new machines and equipment.		Mot, Mem
9	think the number of assessments in the module is appropriate.	Assessments	Mot
10	think the modes of assessments (presentation, report writing, making prototypes, etc.) are appropriate.		Mot
11	think the preparation time for each assessment is sufficient.		Mot
12	have a good understanding of the process of product development.	Applicability	Mot, Mean
13	feel more confident to handle technical tasks in the future.		Mot, Mean
14	feel more confident to draft a business plan for a good idea in the future.		Mot, Mean
15	find it satisfying to push myself beyond my comfort zone when doing the project.	Self-fulfilment	Mot, Mem

16	find it satisfying to see my idea turns into a design and finally to a working prototype.		Mot, Mem
17	am able to apply the knowledge and skills learnt from other modules on the project.		Mot, Mean
18	feel that the modules are enjoyable.		Mem
19	this is a control question, please choose number four.	Control Statement	N.A.

BIOGRAPHICAL INFORMATION

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DESIGNING AN INTRODUCTORY FIRST-YEAR COURSE FOR AN ELECTRONICS ENGINEERING PROGRAM

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ABSTRACT

We present the design and evolution of our current first-year introductory course for the Electronics Engineering program of the School of Engineering at the University of Concepción, Chile based on CDIO Standard 4. For the last eight years, we have gathered student reactions and opinions about the course, recording how its different activities have impacted both their interest in and knowledge of their chosen field of study. These activities have changed throughout the years and have included, in no particular order, talks by faculty members about their research, presentations by practicing electronics engineers about their day-to-day jobs, visits to local industries, individual and small-group programming projects, latter-year student presentations about their internships, junior and senior engineers and alumni talking about their first jobs, and others. Evidence gathered through yearly surveys show that students appreciate the course as they enjoy working in small-group programming projects and hands-on laboratories and also because it gives them the chance to meet and work with their classmates. This was particularly important for the 2020 and 2021 cohorts, when all class activities migrated to virtual platforms. Thus, we have designed a three-part 17-week long course. A six-week college induction course is followed by lab sessions where students work in small groups on electronics programming projects using microcontroller boards such as Arduino Uno, BBC Microbit and/or Raspberry Pi. These lab sessions are interspersed with presentations by practicing junior and senior electronics engineers, mostly alumni, talking about their first jobs and current work. Finally, the course's last weeks are reserved for student poster presentations about the electronics engineering field. Student opinions about this new course design have been encouraging, as it has been well received by the incoming student class.

KEYWORDS

Introductory course, Student satisfaction, Electronics Engineering, Standards 2, 4.

INTRODUCTION

As most Chilean engineering programs (Vial, 2005), the Electronics Engineering program of the School of Engineering of the University of Concepción is six years in length, divided into three two-year cycles. The first cycle is aimed at building strong foundations in math and sciences: first-year students take rigorous courses on algebra, calculus, physics and chemistry. During the second two-year cycle, students take mandatory courses covering several topics in electronics engineering, such as semiconductors, digital systems, electronics, process control systems, etc. Finally, in their last two-year cycle, students choose their elective courses both to specialise their technical knowledge and to broaden their horizons. The program's last term is wholly dedicated to a semester-long individual project that tests students' skills and knowledge by conceiving, designing, implementing and evaluating their solution to an electronics engineering problem of their choosing.

In recent years, there has been a nationwide concerted effort to shorten engineering programs. Therefore, since 2020 all engineering programs at the School of Engineering of the University of Concepción are 5 1/2-year programs. Student feedback gathered via surveys and focus groups showed us that student motivation and enthusiasm were negatively affected by the math- and science-heavy courses, especially during the first two-year cycle. These courses are taught by the School of Math and Physics and follow a scientific curricular approach rather than an engineering-oriented approach. Another revealing insight was that many students did not become properly acquainted with their chosen field of study until the second two-year cycle, and did not fully understand their future role as engineers until the last two-year cycle. Both these factors resulted in most engineering programs having a relatively high attrition rate: on average, 1 out of 4 first-year engineering students left their chosen program either by quitting, changing their majors or being dismissed because of their low grades (Higher Education Information Service, 2021).

How to encourage student interest in their field of study? The Electronics Engineering program has been using the CDIO Standard 4 as a guideline to design its Introduction to Electronics Engineering course, aimed at introducing students to the practice of engineering and to the electronics engineering field. The course, which has undergone several iterations, also focuses on the development of those personal and interpersonal skills and attitudes needed for their academic and professional development. We found several works in the CDIO Knowledge Library to be useful references, such as Roslöf (2008), Loyer et al. (2011), Muñoz, Martínez, Cárdenas, and Cepeda (2012), Vega, Morales, and Muñoz (2013), Vargas (2014), Correal *et al.* (2016), and Schrey-Niemenmaa and Piironen (2017). This introductory course was initially offered as a first-year voluntary-enrolment course for extra credit, and was used as a pilot test bed to try out different activities on first-year students and thus find out the best format for the course. In the following section, we describe the different versions of this course in more detail.

THE INTRODUCTION TO ELECTRONICS ENGINEERING COURSE

2015-2018 course versions

The Introduction to Electronics Engineering course has gone through several iterations since its conception. Its first version was offered in 2015 as a semester-long voluntary enrolment course for first year students only. The course met once a week for two hours and was graded based on class attendance as pass/fail. Student activities typically involved small-group development activities, topical lectures by their future teachers, current research presentations by professors, alumni talks about their future career prospects, among others. Not all first-year students enrolled in the course: only 33 of the 48 students in the freshman class of 2015 signed up for it. Even though the course was graded pass/fail based on attendance, 5 students failed the course. As course enrolment was voluntary, these students were not required to take the course again. The 2016 version of the course was similar. Enrolment was 42 students out of a cohort of 55, of which only 3 students failed the course. For the 2017 version of the course, 37 students out of a possible 48 enrolled in the course. Course requirements were made stricter, so 12 students failed the course.

2019 course version

The four versions of the Introduction to Electronics Engineering course described above were very helpful for determining topics that both interested and motivated students, as well as to identify lecturers who could successfully engage with first-year students and stimulate their interest in the field. However, the logistics of coordinating a 17-week semester-long course alongside the rest of the first-year 12-week trimester courses proved to be a major problem, creating calendar conflicts and confusion among students and teachers. Thus, for 2019 a 12-week trimester course was planned, which included fewer talks and lectures so as to fit the course material into 12 weeks. As a result, many small-group development activities were removed. This trimester-long voluntary course had an enrolment of 39 students out of the 2019 cohort of 51.

2020 course version

From 2017 to 2019, all School of Engineering programs went through a curricular redesign process to shorten program duration to 11 semesters. As a result of this process, all programs now include an introductory course to the program's discipline. This mandatory course meets for two hours a week and is graded as all other program courses. Student feedback about their experiences with the voluntary enrolment course from 2015 to 2019 had shown us the usefulness of our Introduction to Engineering course and its effects on first-year student motivation and overall satisfaction with the program. At the same time, feedback from the trimester-long 2019 version of the course indicated that first-year students missed the small-group development projects of the Introduction to Engineering course: these activities improved morale and motivation, and helped build camaraderie and esprit de corps among them. Consequently, a second course was designed for the second trimester of 2020. In this course, students would work in groups to develop electronics prototypes based on Arduino boards. Unfortunately, the COVID-19 pandemic derailed these plans, as classes were cancelled nationwide. In-class group activities and lectures were suspended and replaced by virtual classes and meetings via Microsoft Teams. An Introduction to Electronics Engineering course was taught during the first trimester of 2020, consisting mainly of virtual lectures via Microsoft Teams, while we studied ways in which students could work remotely in small-group projects and still be able to develop their personal and interpersonal skills. So, we designed a second trimester-long course in which students worked in small groups to develop Android apps using AppInventor (http://www.appinventor.mit.edu), an online web-based integrated development environment that uses intuitive visual programming where students can build fully functional apps for smartphones and tablets (Wolber, Abelson, Spertus, & Looney, 2014), (Patton, Tissenbaum, & Harunani, 2019). Both these courses were mandatory and had full enrolment. As with most courses, student grades are at an all-time high, as are overall student retention rates. These courses had an enrolment of 53 students, of which 43 are still active program members.

2021 course version

In 2021, all School of Engineering programs modified their first year of study so as to do away with its division into three trimesters and revert to a two-semester year. In accordance to this change, the 2010 Introduction to Electronics Engineering trimester courses were successfully merged into one semester-length course, during which students again worked in small groups to develop simple Android apps. Given the restrictions placed on in-person activities by the COVID-19 pandemic, this course was taught online via Microsoft Teams.

COURSE ACTIVITIES

In the previous section, we briefly presented six versions of our Introduction to Electronics Engineering course, without going into detail of the student activities for each one. As mentioned before, the exploratory nature of these courses allowed us to experiment with course contents and activities, and to try different approaches every year. This section describes many of these activities. Not all students engaged in all the activities mentioned below: in particular, the peculiar nature of university activities during the COVID-19 pandemic these last two years has precluded many of them.

Introduction to University life University staff talk to students about the opportunities and challenges associated to leaving their homes and adapting to university life, covering topics such as common computer software, University computing resources, etc.

Introduction to the University Library system: Students visit the library for the first time. During the pandemic, University Library staff reviewed access to online books and databases.

The Electronics Engineering field: The program head goes over the Electronics Engineering field reviewing future prospects and fielding questions from students.

University rules and regulations: The program head reviews relevant university rules and regulations, covering everything from the credit system to the university's grievance reporting system.

Student wellness: Staff from the University's Student Wellness Centre talk to students about how to face the physical and mental challenges of living away from home

Student inclusion and diversity: Staff from the University's Inclusion Program talk to students about equal access to opportunities and resources for people having physical or mental disabilities and members of minority groups.

Student relationships: Staff from the University's Gender and Diversity Centre talk to students about healthy student relationships and the University's rules and regulation regarding these matters

Professional ethics: Lecturers talk to students about professional ethics and its implications, discussing recent case studies

Alumni talks: Alumni are invited to talk to students about their experiences as a student in the Electronics Engineering program, and to describe their day-to-day jobs as electronics engineers

Recent graduates' talks: Recently graduated students come back to school to talk to students about their job-seeking experiences, their first jobs and to reflect on the program

Talks by summer interns: Students who enrol on summer internships are encouraged to talk about their experiences to first-year students, showing them photographs and videos of their workplace and activities

Faculty research talks: Many faculty members are eager to showcase their work and talk about their research to first-year students. This also gives students an overview of the field's state of the art.

Field trips: Students tour nearby industrial plants and gain in situ knowledge of the role of the electronics engineer in that particular business

Group research projects: Students work in groups to research topics of interest in electronics engineering, presenting their work to the class

Student group essays: Students work in groups to research topics of interest in electronics engineering and collaboratively write essays about them

Android app development: In 2020 and 2021 students worked collaboratively to design and develop apps for Android using a web-based integrated development environment

DATA GATHERING METHODS

To evaluate the effectiveness and usefulness to students of the above-mentioned activities, we have periodically surveyed all active program members who took the Introduction to Electronics Engineering course in any of its seven versions. Of this universe of 272 students, 146 answered the survey. Figure 1 shows our preliminary survey results. It should be noted that not all students had the opportunity to do every activity: for example, only two of the seven courses included a field trip. Thus, results are given as a percentage of the total number of students who engaged in a certain activity and then answered the corresponding survey question.

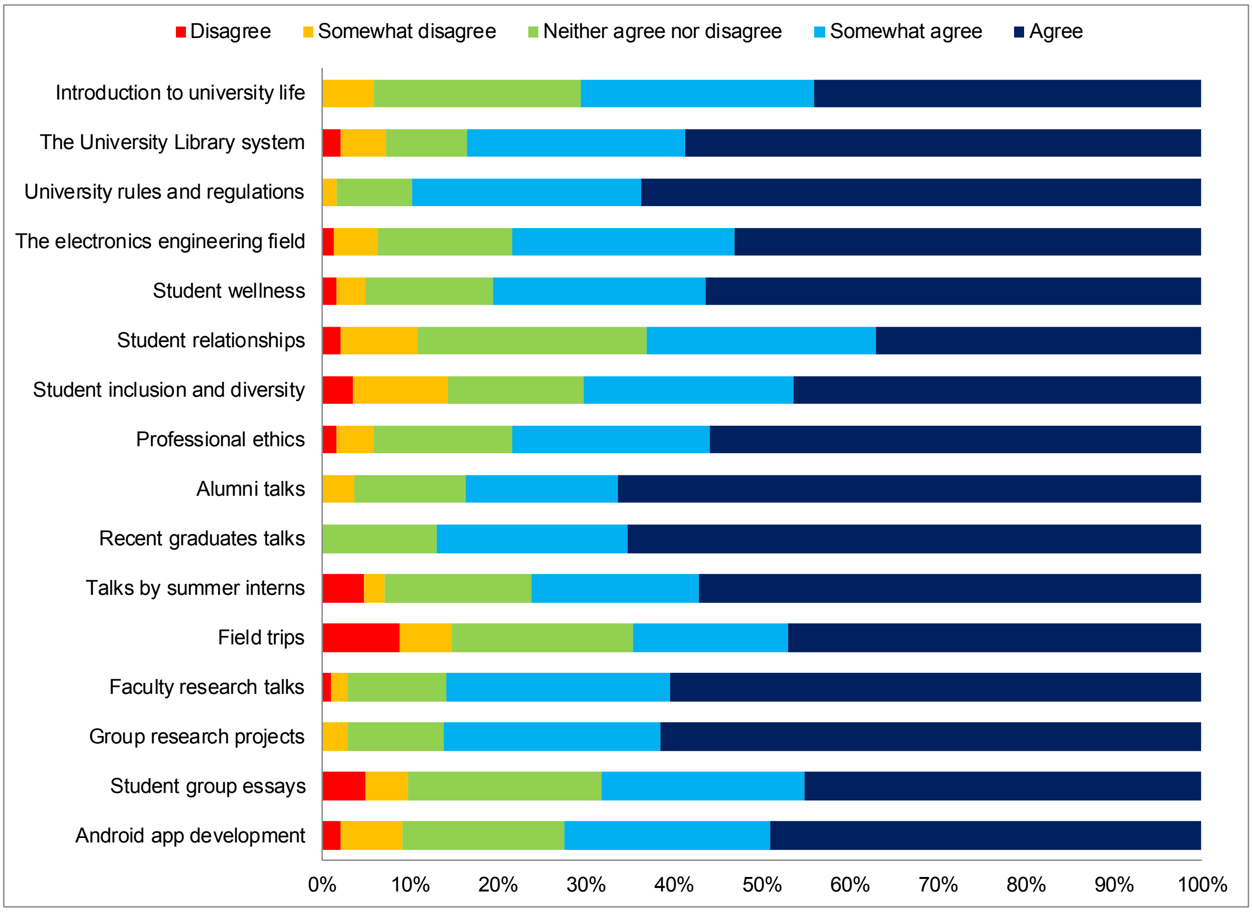

Figure 1. Student perception of introductory course activity usefulness

As can be seen in Figure 1, students in general consider those course activities they engaged in as useful and informative. Most students highly value induction activities such as the University rules and regulations review, the Introduction to University Life presentation and the overview of the electronics engineering field. Likewise, first-year students find that faculty research talks, alumni talks and recent graduates' talks are interesting and topical. On the other hand, most talks about student relationships, student wellness, inclusion and diversity given to first-year students by University personnel were not as well received. Hence, we are working with the corresponding University units to design more interesting and relevant presentations. Finally, those few activities that were graded (student group projects, student research projects and the development of Android apps) were considered somewhat less useful and enjoyable.

Regarding the course workload, any first-year students report problems with time and resource management, and with teamwork and work distribution among their classmates. However, these problems are usually associated with the math- and science-heavy course: this introductory course is seen by students as a lighter-load course. Both the University and the School of Engineering have long-standing student support programs to help those students that struggle with their transition from high school to university.

Students were also asked to report on their perception of the effects of the Introduction to Electronics Engineering course via a follow-up survey taken after the course is finished. Figure 2 shows some of our aggregated preliminary results.

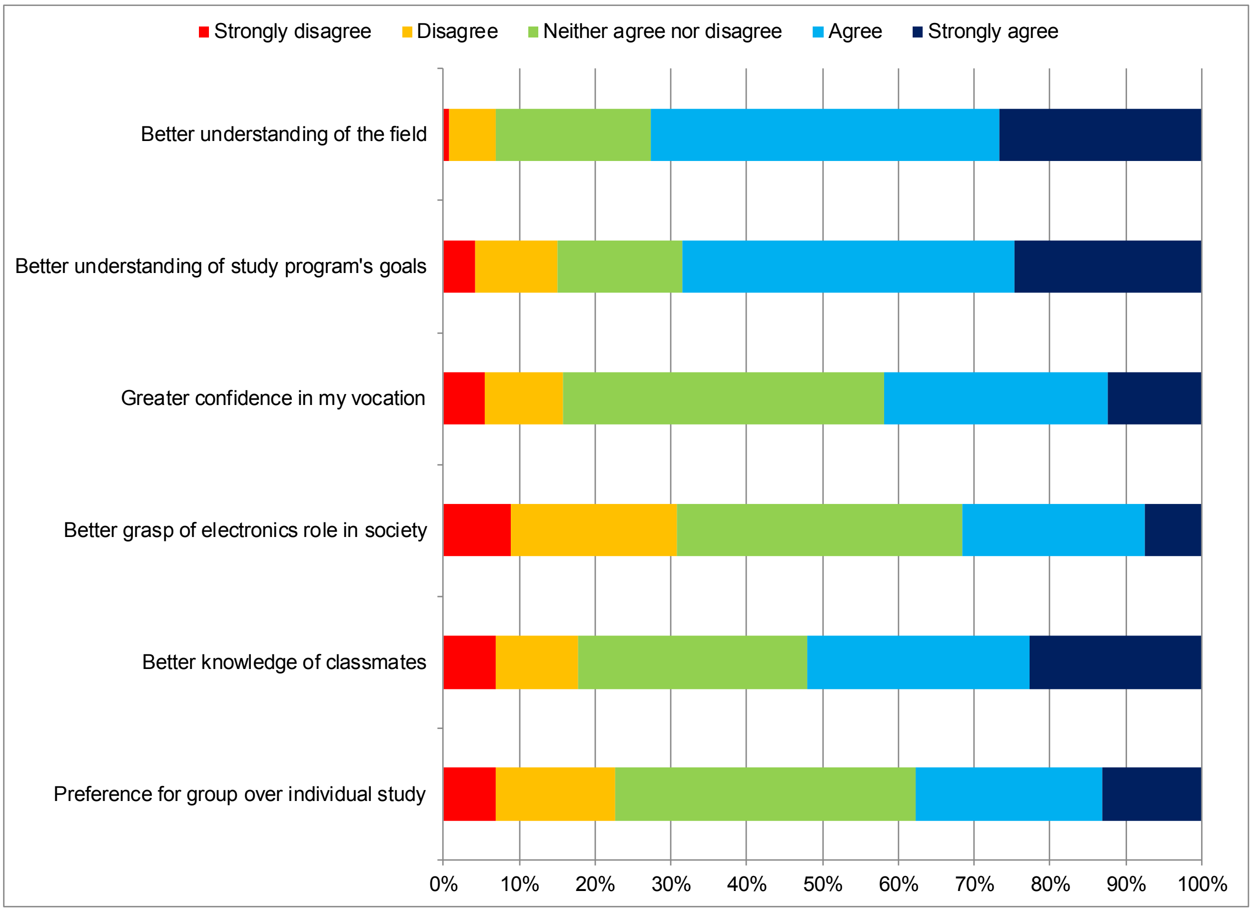

Figure 2. Student perception of introduction to Electronics Engineering course

On the whole, as can be seen in Figure 2, students perceive their Introduction to Electronics Engineering course as a pathway to a better understanding not only of the Electronics Engineering study program which they have just joined, but also of the electronics engineering field itself. However, they still do not have a firm grasp on the role of the electronics engineer in society and industry. This uncertainty does not help them identify and define their skilful vocation yet. While this course may have not convinced many of our students that electronics engineering is their vocation, this new understanding of the field might yet help them fall in love with their chosen field of study.

Also, from Figure 2, it can be seen that through this course our students have met their classmates, worked together on some simple projects and are starting to appreciate the value of teamwork. This has been especially important for the 2020 and 2021 cohorts, who, because of the COVID19 pandemic, were not able to meet their classmates in person until March of 2022, after in-person restrictions were lifted. Even so, in-class facemask use was mandatory until the second semester of 2022. Thus, our Introduction to Electronics Engineering course allowed for student engagement, interaction and teamwork in a lower-pressure environment than the other math- and science-heavy first year courses.

DESIGN OF AN INTRODUCTORY FIRST-YEAR COURSE

Throughout this paper, we have presented the design and implementation of an introductory Electronics Engineering course for first-year students and its different versions, from 2015 to date. The optional nature of these courses has allowed us to experiment with different formats and activities. The effectiveness and usefulness of these modifications have been assessed via student satisfaction surveys not only at the end of the course, but lately also through a retrospective survey given to latter-year students.

The current version of the course is now a mandatory semester-long course divided into roughly three parts. The course starts with a six-week college induction section including a series of lectures introducing the university and its services, the electronics engineering study program and the electronics engineer's role in industry and society. Additionally, some University-mandated lectures on student relationships, inclusion and diversity are included.

The second part of the course aims to give students a taste of the hands-on lab work they will experience in later years. These lab sessions are interspersed with presentations by practicing junior and senior electronics engineers, many of them alumni, talking about their first jobs and their current work. The University's cautious return to normal activities after the pandemic meant that facemasks had to be worn in class at all times by professors and students, and that in-person laboratory work was severely limited. Likewise, all field trips were cancelled. Therefore, in 2022 the hands-on lab work was replaced by Android app development using Kodular (Kodular, 2022), an improved version of the AppInventor development environment.

Finally, the course's last weeks are reserved for student poster presentations about the electronics engineering field and for talks and presentations by faculty, alumni and engineering practitioners aimed at giving students food for thought about the field's promise and their professional future. Additionally, we have older students act as role models to younger students by having them give poster presentations about their internships, as hopefully these may help first-year students' motivation and interest in the field. Furthermore, we have embraced the latest new-fangled technologies to have engineers talk to students from their place of work and to build a video repository in the cloud for future reference.

Student opinions about this new course design have been encouraging, as it has been well received by the incoming student class. The renewed focus on presentations, either in person or via video, by practicing engineers and alumni talking about their work history has been appreciated and commented upon by our first-year students. At the same time, this year's students have been critical of the Android app development focus, clamouring for more electronics and less programming. We aim to do that in the 2023 version of the course by focusing this year's lab work on using the Micro:bit microcontroller card. Likewise, we intend to bring back the yearly field trips to nearby industries, another common request we hear from our students.

CONCLUSIONS AND FUTURE WORK

Throughout this paper, we have presented the design and implementation of an introductory Electronics Engineering course for first-year students. We have also presented preliminary survey results for all students that have enrolled in the different versions of this course since 2015. The current version of the course is now a mandatory semester-long course divided into roughly three parts: a series of lectures that serve as an induction to the university, the program and the field of study, talks and presentations by faculty, alumni and engineering practitioners aimed at giving students food for thought about the field's promise and their professional future, and a series of graded group activities for students to work together, thus developing their personal, interpersonal and teamwork skills. This course runs parallel to their math- and science-heavy first year courses and is their first introduction to the practice of engineering.

For 2023, we will replace the Android app programming experiences, which were appropriate for online classes, with lab sessions where students work in small groups on electronics programming projects using microcontroller boards. For 2023, we have chosen to use the Micro:bit v2 board, an open source hardware ARM-based embedded system designed by the

BBC for use in computer education in the United Kingdom. This board was chosen for its versatility, robustness and low cost, and it has an ARM Cortex-M4 processor, several sensors such as an accelerometer, a magnetometer, and a touch sensor button, and includes a microphone and speaker, programmable buttons, USB and Bluetooth connectivity and a 25-LED display. The Micro:bit board is programmable via Microsoft MakeCode, a graphical blocks language, and via MicroPython.

Furthermore, starting in 2022, during their second semester students enrol in a School of Engineering-wide Innovation course, where they will work in teams with students of other engineering disciplines on problem solving using Design Thinking. There they work on devising simple engineering solutions to multidisciplinary problems and it is expected they will use the Micro:bit board as a microcontroller in their designs.

Our survey results also show that students' perception of the Introduction to Electronics Engineering course change with the years since the course was taken. First-year students get the most out of the induction part of the course, as they lack familiarity with university life, the campus, the study program and the university's rules and regulations. At the same time, older students who now understand the field better may look back and now appreciate the faculty research lectures, and the alumni and practicing engineers' talks. More work is needed to explore these topics and we intend to continue evaluating the course's effectiveness and usefulness to students in the future, so as to adapt it as needed. We are currently using these and other results to inform syllabus design for the 2023 version of this course, which we hope will incorporate both in-person lectures and video talks.

Finally, we feel that through the process described above we have designed an introductory Electronics Engineering course that provides the framework for the student's future engineering practice, while aiding the development of students' essential personal and interpersonal skills such as teamwork and collaboration (CDIO Standard 4). As future work, we intend to update the course by adding discussion of the rationale of sustainability in the context of engineering, as discussed in Malmqvist, Edström, and Rosén (2020). Finally, the School of Engineering is working with the School of Math and Physics to improve horizontal coordination and further contextualize their first-year course.

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PYTHON IN A WEEK — CONCEPTUAL TESTS FOR LEARNING AND COURSE DEVELOPMENT

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ABSTRACT

Programming has gradually become an essential skill for engineers and scientists across disciplines and is an important part of the CDIO Syllabus covering fundamental knowledge and reasoning. Recently, there has been a shift away from introductory programming languages like C and Java towards Python, especially in programs where the focus lies on handling and analysing large quantities of data, such as energy technology, biotechnology, and bioinformatics. This paper illustrates the successful setup of a one-week-long introductory Python programming course with a hands-on approach. Given the limited time, a challenge is how to effectively teach students a meaningful set of skills that enables them to self-guide their future learning. Moreover, since the course does not include any summative assessment, we need other means of measuring students' learning and guiding course development. We address these challenges by coupling short lectures with short quizzes for formative assessment, adding another learning activity to the course. We find that, in the absence of summative assessment, short, frequent quizzes with immediate feedback are an excellent tool to track the learning of a class as a whole. Students report that the quizzes, albeit challenging, improved their understanding of programming concepts, made them aware of potential mistakes, and were a fun learning experience. Furthermore, the results from this paper illustrate how a new programming language can be taught to students without prior programming skills in a short period of time. We summarise our lessons learnt for designing and integrating quizzes in short-format programming courses.

KEYWORDS

Python programming, conceptual test, formative assessment, Standards: 2, 4, 7, 8, 10, 11

INTRODUCTION

The CDIO framework (Crawley, Malmqvist, Östlund, & Brodeur, 2007) mentions knowledge and skills that need to be part of the syllabus for our students to enable them to conceive, design, implement, and operate in their future professions. In the CDIO syllabus 3.0 (Malmqvist et al., 2022), *Personal and professional skills and attributes* (2) are emphasised, including everything from fundamental skills to creativity and ethical responsibility. Under *Analytical reasoning and problem-solving* (2.1) and *Experimentation, investigation and knowledge discovery* (2.2), there are many important parts that focus on modelling, analysis, and other aspects requiring good skills within data manipulation, that is, programming skills, for providing high-quality results and solutions. Consequently, not only the ability to use computers defines successful engineers but the ability to program computers. Having basic skills within programming provides a better foundation for engineers across disciplines to solve complex problems (e.g. Ball & Zorn, 2015).

Today, many different programming languages are taught to students, chosen depending on what skills are required within their discipline. For example, computer scientists need to be able to implement highly-efficient programs for complex real-world business applications and often learn C/C++ or Java, both of which are widely adopted in the industry. Physicists and engineers create models for running simulations and computations, typically using languages like C++ for efficient implementations, or MATLAB because it is specialised for numerical computations. Common tasks for data scientists include pooling data from various sources, performing statistical analyses, automating workflows, and visualising results, often done in languages such as R and Python. During recent years, academia has started to shift away from "traditional" introductory programming languages towards Python. Reasons for this shift include Python's simple syntax which makes it easy to learn and its increasing relevance in industry (Bogdanchikov, Zhaparov, & Suliyev, 2013; Cheng, Jayasuriya, & Lim, 2010; Jayal, Lauria, Tucker, & Swift, 2011; Leping et al., 2009; Mannila, Peltomäki, & Salakoski, 2006). Moreover, the abundance of available Python libraries for statistical analyses, machine learning, and visualisations has made Python a common tool across disciplines and a de-facto standard for data scientists.

In this paper, we describe how we have designed short quizzes and incorporated them into the setup of the one-week long course *Introduction to Python — with Applications in Bioinformatics* offered by the National Bioinformatics Infrastructure Sweden (NBIS) to the Swedish research community. Our quizzes are tightly coupled with the lectures' topics and inspired by the principles behind concept inventories (Taylor et al., 2014); their purpose is to help teachers identify and address students' misconceptions to improve their conceptual programming understanding. The first version of our quiz, which we made available on GitHub, contains 21 questions. We used the learning management system Canvas to run the quizzes and provide immediate feedback to the students, explaining why their answers were correct or incorrect and discussing the remaining open questions in class. Using the quizzes for the first time in 2022, we found that they work well as a learning activity, help improve students' conceptual programming understanding, and provide insights for improving teaching material.

RELATED WORK

According to Robins, Rountree, and Rountree (2003), teaching programming involves programming-language-specific knowledge, problem-solving strategies, and mental models of the problem and program domain to enable students to design, implement, and evaluate solutions. Traditional programming courses are often knowledge-driven and use textbooks focusing on presenting syntactic and semantic knowledge, supported with examples and exercises. However, problem-based instruction has been found to improve student learning. For example, Cheng et al. (2010) suggest focusing on analysing, decomposing, and solving problems instead of merely memorising programming syntax. They approach teaching programming from a constructivist approach, letting students learn and draw their own conclusions through experimentation. Vial and Negoita (2018) emphasise that learning programming is a social activity, which has implications for choosing teaching strategies and assessments. They propose a course setup with Python, Jupyter notebooks, and GitHub to facilitate collaboration and make programming an active engagement with others.

Vial and Negoita (2018) argue that teaching programming to non-computer science students removes certain constraints: Theoretical foundations that are part of traditional computer science curricula need not be covered as rigorously. They suggest focusing on solving problems in a specific domain instead of, as commonly done, teaching programming without considering an application context. Mironova et al. (2015) agree that problems should be selected based on the students' discipline. Vial and Negoita (2018) emphasise that the main objective of teaching programming to non-computer science students is not to educate future programmers, but rather teach students to think like programmers and develop computational thinking skills. However, different from our situation, programming courses for non-computer science students often aim at first-year students who are not yet domain experts in their field of study and typically span a whole semester (Cheng et al., 2010; Mironova, Amitan, Vendelin, Vilipõld, & Saar, 2016; Mironova et al., 2015; Vial & Negoita, 2018).

Concept inventories are tools that help teachers identify students' misconceptions through a set of open or closed-ended questions and problems (Taylor et al., 2014). They are well-established in physics education to assess students' understanding of concepts such as force (Hestenes, Wells, & Swackhamer, 1992), mechanical waves (Caleon & Subramaniam, 2010), or electricity and magnetism (Maloney, O'Kuma, Hieggelke, & Van Heuvelen, 2001), but have also been systematically studied and applied for computer science education in general, and, more specifically, for teaching Python (Johnson, McQuistin, & O'Donnell, 2020; Kaczmarczyk, Petrick, East, & Herman, 2010; Taylor et al., 2014). Independent of the subject, misconceptions can cause a significant challenge for students and hinder their ability to understand and apply concepts and principles. Therefore, identifying and addressing misconceptions is critical for ensuring that students have a strong foundation and are able to apply their knowledge effectively. In programming, misconceptions can arise due to a variety of factors, including differences in the semantics of the same word in programming and natural language, prior math knowledge, flawed mental models regarding how a computer executes code, inadequate problem-solving strategies, or, more generally and from a constructivist point of view, the entirety of students' previous experience (Qian & Lehman, 2017; Robins et al., 2003).

COURSE SETUP

Introduction to Python — with Applications to Bioinformatics is a one-week-long course offered to the research community in Sweden by NBIS, and aimed towards bioinformatics and data science, thus focusing mostly on usage and understanding of code, rather than an in-depth un-

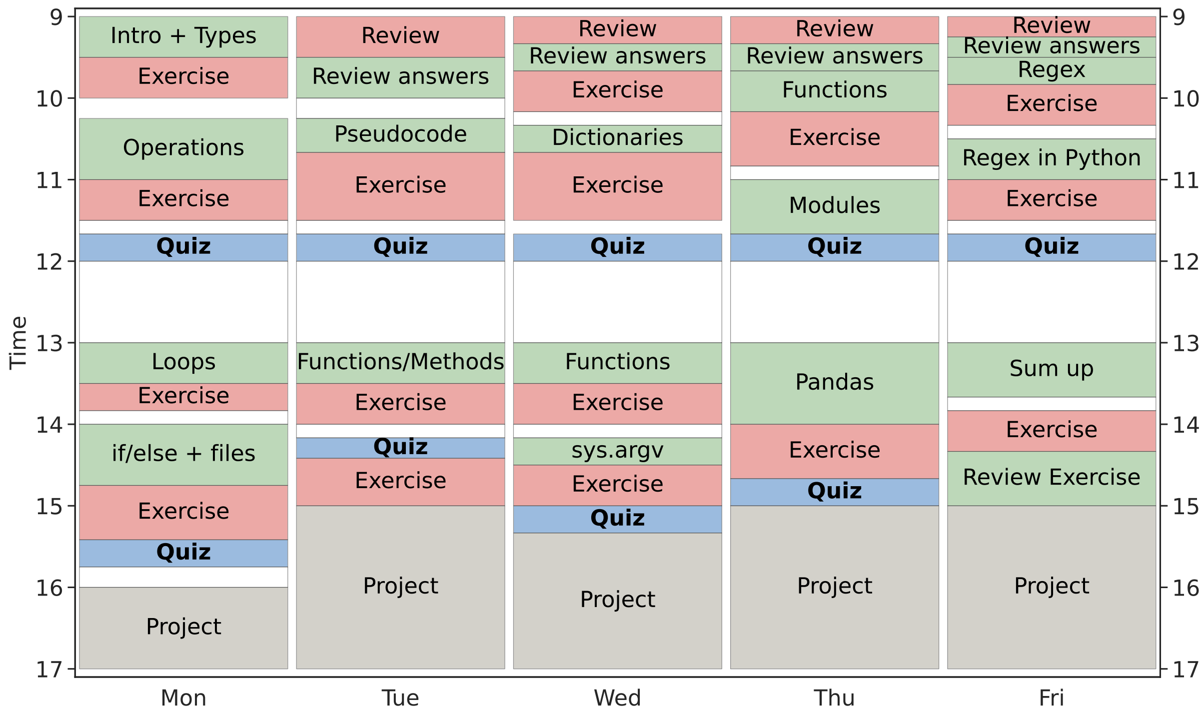

Figure 1. Course schedule where lectures are shown in green, exercises in red, quizzes in blue, and project sessions in grey. Each quiz session is thematically coupled with the previous lecture. Between lectures and quiz sessions, students have the opportunity to revisit and practice new material in the exercises.

derstanding of underlying computer science principles. The course assumes no previous programming knowledge and aims to bring students' knowledge to a level where they can directly apply Python and continue learning Python on their own. Achieving this level of understanding in one week is challenging and requires an effective course setup: we group short informative lectures together with practical exercises aimed at solidifying the students' new knowledge. In a hands-on project that spans the entire week, students work on an open-ended real bioinformatics problem, albeit simplified to fit the course's time frame, and put their newly learnt skills to work. To continuously monitor the effectiveness of this setup as well as students' learning, we have designed short formative quizzes that are thematically coupled with the lectures, and that the students answer in two quiz sessions per day (Figure 1). The learning outcomes for *Introduction to Python — with Applications to Bioinformatics* are listed in Figure 2.

NBIS, which is part of the Science for Life Laboratory (SciLifeLab), has several learning paths for becoming an expert bioinformatician or data scientist and offers a range of courses including *Neural Networks and Deep Learning*, *Omics Integration and Systems Biology*, *Single Cell RNAseq Data Analysis*, and *Advanced Python*. NBIS' courses contribute to life-long learning for researchers at all career stages, targeting mainly PhD students and postdoctoral researchers, and are a continuation rather than a part of formal education; therefore they do not contain any formal assessments. Because Python has become an important foundation in data science, all of the above courses use Python and build on *Introduction to Python — with Applications to Bioinformatics* or equivalent knowledge as a prerequisite (Figure 2).

- Use variables and explain how operators work
- Process data using loops
- Separate data using if/else statements
- Use functions to read and write to files
- Describe their own approach to a coding task
- Understand the difference between functions and methods
- Be able to read the documentation for built-in functions/methods
- Give examples of use cases for dictionaries
- Write data to a simple dictionary
- Understand concept and syntax of functions
- Write basic functions for processing data
- Describe pandas dataframes
- Give examples of how to use pandas for processing data
- Explain how regular expressions can be used
- Define Python syntax for regular expressions
- Combine basic concepts to create functional stand-alone programs to process data
- Write file processing programs that produce output to the terminal and/or external files
- Explain how to debug and further develop your skills in Python after the course

Figure 2. Learning outcomes for *Introduction to Python — with Applications to Bioinformatics*.

QUIZ DESIGN

Creating a concept inventory typically involves four steps: setting the scope, identifying misconceptions, developing questions, and validation (Goldman et al., 2010). In our case, we use the course's learning outcomes to set the scope. We have identified misconceptions and developed questions connected to each lecture topic with the purpose to improve students' learning by confronting them with related, but slightly more advanced situations. Our questions aim to prepare students for typical programming challenges and common mistakes they are likely to face when applying their programming knowledge in day-to-day work. To achieve this, we designed our quizzes based on three sub-goals: they should (i) test higher-level cognitive processes according to Bloom's revised taxonomy (Krathwohl, 2002), (ii) help identify students' programming misconceptions, and (iii) provide insights for improving the course.

First, we aimed to test students' higher-level cognitive abilities according to Bloom's revised taxonomy, more specifically their ability to *analyse* and *evaluate* Python code and to make predictions about the result that a piece of code produces. We did not cover the *create* level because it is addressed by the hands-on project; we regard the quizzes as an additional learning activity that helps prepare students for applying the learnt programming knowledge in real situations. To ensure that the quizzes test the intended Bloom's level, we purposefully designed questions that go beyond the material discussed in the lectures. Otherwise, students could answer the questions by simply recalling the respective information without activating higher-level cognitive processes. Instead, we require students to combine several concepts that were discussed in the lectures in a new way. For example, Figure 3 shows a question that tests students' understanding of variable scopes. Before answering this question, the students had learned about variables, functions, and scoping rules.

Second, we wanted to use the quizzes in a similar manner as concept inventories are used, that is, as a tool that helps teachers identify students' misconceptions, and address them in a timely manner. Therefore, we have coupled the quizzes with the lectures and run quiz sessions twice per day, one in the morning and one in the afternoon (Figure 1). However, between the lectures

x = 1	What does the code print?	Students answered
y = 2	(a) 1,2,4	(a) 0%
def my_function(x):	(b) 1,4,8	(b) 31%
x *= 2	(c) <u>1,4,16</u>	(c) 38%
return x*y	(d) 2,4,4	(d) 0%
y = 4	(e) 2,4,8	(e) 8%
z = my_function(2)	(f) 2,4,16	(f) 23%
print(x,y,z)		

```
x = 1
y = 2

def my_function(x):
  x *= 2
  return x*y

y = 4
z = my_function(2)
print(x,y,z)
```

Figure 3. Scopes of local and global variables. A code snippet is shown on the left, possible outputs in the middle with the correct answer underlined, and students' answers on the right.

and quizzes, students have time to revisit and practice new material in short exercises. We designed the possible quiz answers so that they all appear plausible while incorrect answers point out what misconception a student holds. For implementing the quizzes in practice, we used the learning management system Canvas because it enables providing immediate feedback. The immediate feedback helps students understand their misconceptions, allowing them to refine their mental models if necessary, which plays an important role in making the quizzes an effective learning experience.

Third, we intended the quizzes as a way to collect feedback for improving lecture and exercise content to teach programming concepts more effectively. Collecting answer statistics through Canvas provides a basis on which we can identify the most common misconceptions to develop our teaching material accordingly.

In total, we designed a quiz with 21 questions that we split up into 9 quiz sessions. The complete set of questions is available online[1]. To summarise, our quiz addresses higher-level cognitive processes by requiring students to combine learnt knowledge in new ways, helps identify misconceptions and refine mental models, and provides a basis for improving course content.

USING THE QUIZ AND STUDENTS' RESULTS

Introduction to Python — with Applications to Bioinformatics has been running for several years, but 2022 was the first time we used our quizzes as a learning activity. In 2022, there were 24 students from all over Sweden who took the course, mostly PhD students and postdocs. Their prior knowledge ranged from never having done any programming to knowing another programming language. On average, students answered 52% of the questions correctly (Figure 4a).

For example, 38% answered the scoping question (Figure 3) correctly. However, 39% answered that z has value 8 when printed, indicating that they have a misconception regarding when the value for y is accessed: at the time when my_function is defined, y holds the value 4, which would indeed result in setting z to 8. But at the time my_function is executed, the global variable y holds the value 4, which is used when assigning a value to z. 31% answered that x has value

[1] https://github.com/chrisbloecker/python-in-a-week-quiz

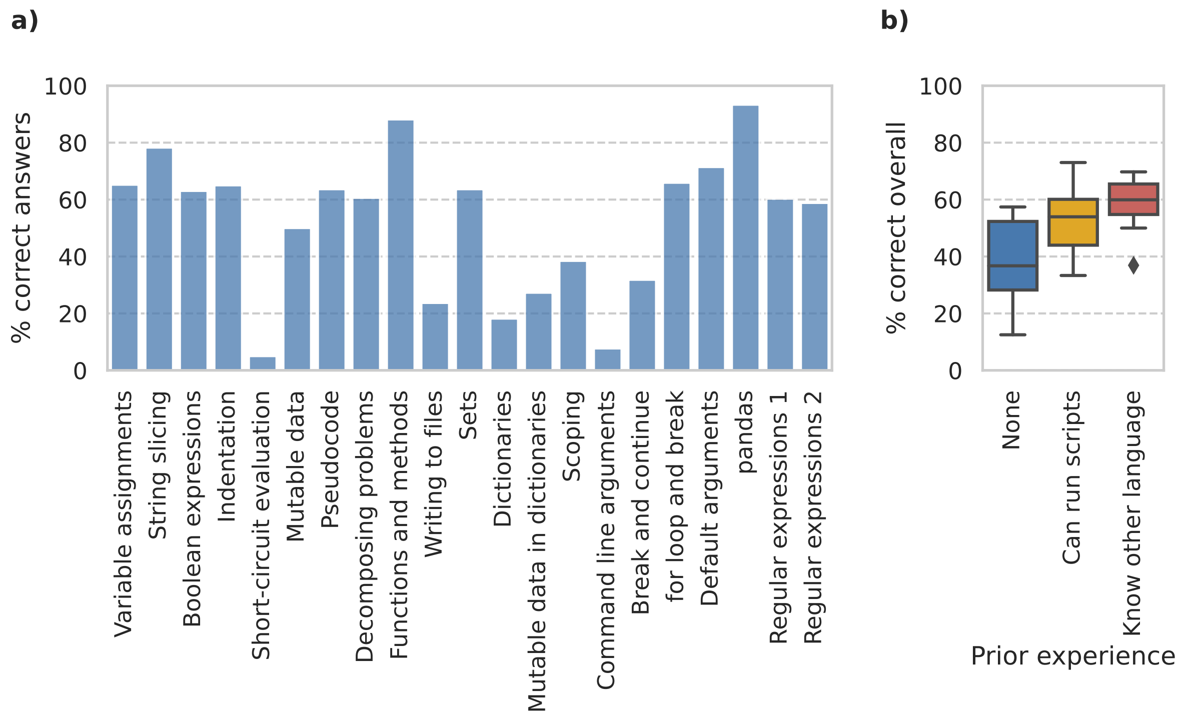

Figure 4. Quiz results and prior experience. **a)** Percentage of students answering the questions correctly. Questions are arranged in the same order as they are presented to the students during the course. **b)** Overall quiz results per student, separated by self-reported prior knowledge.

2 when printed, indicating a misconception regarding variable shadowing: the local variable `x` in `my_functions`'s local scope shadows the global variable `x`, which remains unchanged.

The most challenging question, according to the overall results, was related to *short-circuit evaluation* (Figure 5). A possible misconception source may be the difference between how the logical conjunctions `and` and `or` are used in natural language and formal logic. However, the reason why this question was more challenging is probably how we have formulated the question: we are not interested in a variable assignment for which the condition evaluates to `True`. Instead, we ask for an assignment that prevents the code from crashing. Despite our hint that "not all variables are defined", students seem to forget about the objective and select the variable assignment that evaluates the condition to `True`, happy that `ok` will be printed. Nevertheless, 70% chose answer (d), indicating a good understanding of short-circuit evaluation, highlighting that it is important to be aware of which answers reveal which misconceptions.

From a teaching perspective, the quizzes provided timely insights into students' learning and revealed what parts of the introduced material were challenging. This allowed us to select the most relevant concepts for discussion after each quiz session for clarification. Moreover, the results showed what parts of the lectures require revision for more effective learning. Setting up the quizzes with detailed feedback in Canvas took some time, however, we find that this was time well spent because it allowed giving meaningful feedback to the students. Moreover, once

What variable assignment will prevent this code from crashing? Note that not all variables are defined in all cases.

```
if (a and b) or (not a and c) and (d != e):
    print(ok)
```

(a) a=False, b=False, d=False, e=True (10%)

(b) a=True, c=False, d=True, e=False (15%)

(c) a=False, c=False, d=False, e=True (5%)

(d) a=False, c=True, d=False, e=True (70%)

Figure 5. Short-circuit evaluation of Boolean expressions.

set up, the quizzes require no additional time from the teachers, give instant feedback to both students and teachers when students take the quizzes, and can easily be re-used.

On course signup, students reported their prior programming knowledge, choosing between

- I have never written any code before,
- I can run scripts written by others,
- I know another programming language (for example Perl, Java, R, etc.).

The correlation between prior programming knowledge and overall quiz result suggests that a higher level of prior knowledge tends to lead to a better quiz outcome (Figure 4b). However, because data is sparse, we can only report the results for this particular course instance and drawing general conclusions is not warranted.

In the course evaluation, we asked the students to describe how they experienced the quizzes and their contribution to their learning experience. Overall, they appreciated the quizzes as an activity that enhanced their learning. One student commented that they learned “A lot, it was a good way to practice and digest the info.”. Another student said about the quizzes “They certainly helped me a lot and made me aware of details that I would have otherwise missed.”.

CONCLUSION AND FUTURE WORK

We have designed a basic Python programming quiz consisting of 21 questions and integrated it into NBIS’ introductory Python programming course, *Introduction to Python — with Application to Bioinformatics*. The quiz serves three purposes: (i) it tests students’ higher-level cognitive skills by requiring a combination of several programming concepts, (ii) it helps identify students’ programming misconceptions, and (iii) it provides data for improving the course. We used the quiz for the first time in 2022 when 24 students participated in the course. Despite being challenging, the students reported that the quizzes were a good learning activity and helped them understand programming concepts better.

We summarise our lessons learnt for designing and integrating conceptual tests in the form of a quiz in a short-format programming course:

- It is important to take the time to set up the questions, including detailed feedback on both the right and wrong answers.
- Emphasise for the students that the quizzes are not to be understood as summative assessments, but rather as learning activities. Therefore, they should not feel bad for not answering everything correctly, but rather learn from their mistakes and take the opportunity to improve their understanding.

- Since taking the quizzes was not mandatory, some students did not answer all questions. Make sure to explain the importance to the students, and allocate enough time to finish the quizzes.
- Clarify that the quizzes are supposed to be solved using pen and paper, and running the code through the Python interpreter to get the right answer defies the purpose of the learning activity.

Even though this pilot test has been carried out on PhD students and postdoctoral researchers, we believe that the results are interesting for engineering education. Giving engineering students the possibility to quickly learn basics in a new programming language will create new opportunities to give students more complex tasks in terms of, for example, data manipulation. Furthermore, letting students learn and practice basics in several programming languages during their studies will lower the bar for using those programming languages in their future profession and increase their confidence. Hence, to further extend the results from this study, this concept should be introduced in undergraduate education programs in the immediate vicinity of tasks that benefit from using Python.

Future work that remains to be done is to revise our lecture material based on the students' quiz outcomes and validate the quizzes over a longer period of time with each revision. Long-term follow-up of the students, and how, in their experience, the quizzes have contributed to their knowledge should be done, ideally around 6-12 months after the course is finished.

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PROMOTING CURRICULUM AGILITY THROUGH PROJECT-BASED LEARNING: CASE OF THE AUSTRALIAN UNIVERSITY (KUWAIT)

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ABSTRACT

Curriculum agility has recently drawn the attention of the engineering education sector as it addresses the challenging dynamic nature of engineering markets. Project-based learning (PBL) is foreseen as a successful pedagogy that adds flexibility to engineering curricula and equips graduates with long-life learning skills. The level of flexibility that PBL adds depends on many factors and one of them is the way it is practiced. In this paper, the flexibility added by the currently applied PBL model at the College of Engineering at the Australian University in Kuwait as well as a newly proposed PBL model is assessed from the perspective of experienced PBL facilitators through quantitative and qualitative survey methods. After introducing the two models and the expected enhancements added by the new model on the implementation of CDIO standards, the survey results are presented and thoroughly discussed. The results show that the new PBL model is expected to enhance the flexibility of engineering curricula but also bring to the fore the resilience to change of PBL facilitators and consequently the importance of explanatory and discussion workshops before and during the implementation of new PBL model.

KEYWORDS

Project-Based Learning, PBL, Engineering, Curriculum, Curricula, Flexibility, Agility, CDIO Standards: 1, 2, 3, 7, 8, 9, 10.

INTRODUCTION

With the increased demand for modern life and new technologies from one side and the increasingly dynamic market from the other side, the role of engineering higher education institutions is no longer graduating traditional engineers but instead, educating long-life learners who are capable of coping and quickly adapting to this very agile market while maintaining high quality standards. In addition, the rapid emergence of novel computer aided design, engineering, and manufacturing tools as well as the tremendous shift towards the internet of things and artificial intelligence also re-shape the skills and graduate attributes of tomorrow's engineers.

As curriculum agility is foreseen to address these challenges, higher education institutions are nowadays adopting new pedagogical strategies to add various degrees of freedoms to their curricula, enabling them to embed implicitly or explicitly new skills, concepts, technologies, and tools to their educational framework whenever needed by the market. For some institutions these degrees of freedom are restricted to distance or blended learning where students' diversity is the main motive for providing equal study opportunities and enabling flexibility in the "when" and "where" of learning. On the other hand, others introduce flexibility as reinventing delivery through adopting novel learning approaches focusing on the “what” and “how” of learning such as CDIO (Crawley, Hosoi, & Mitra, 2018) and Project Based Learning (Graaff & Kolmos, 2003).

In alignment with promoting curriculum agility, the College of Engineering at the Australian University in Kuwait is aiming at introducing an enhanced version of the currently implemented Project Based Learning (PBL) model with more flexibility degree of freedoms in the “what” and “how” of learning. The new model consists of PBL courses with agile learning outcomes which are expected to further nurture the student-centered long-life learning approach while enabling students to be exposed to the most recent technologies in the market.

In this paper, this new PBL approach and its alignment with CDIO standards is presented, discussed, and compared to the currently implemented course based PBL approach at the College of Engineering at the Australian University in Kuwait. The results of quantitative and qualitative surveys of PBL experienced facilitators at the Australian University are also presented and conclusions are drawn about the flexibility of both PBL models as well as the challenges that may face the newly introduced PBL approach.

PBL AT THE AUSTRALIAN UNIVERSITY AT A GLANCE

Current PBL Model

PBL is implemented at the College of Engineering at the Australian University since 2015. At that time, and to smoothly integrate PBL within the delivered programs, a course based PBL delivery was considered. Courses which best fit the PBL approach were selected from the existing engineering programs (civil, mechanical, electrical and petroleum engineering), and their delivery mode was changed from traditional lecturing to project-based learning without compromising the structure of the curricula nor the delivery mode of the remaining courses. As such, courses that require hands-on practice were mainly considered, such as programming and design courses. In total, in each engineering program, five courses were changed to PBL, one per semester, distributed over the fourth till the eighth semester of study in addition to one summative graduation project PBL experience during the last year of the program. Since then, the PBL model at the Australian University kept evolving with a lot of attention given to the assessment & feedback strategies that best serve the student-centered approach of delivery from one side as well as the students’ expectations of their learning from the other side (Farhat, Nahas, & Salti, 2020), (Hussain, & Jaeger, 2018). The PBL model was also revised to consider all the requirements of the CDIO framework and in 2018, the Australian University became a member of the CDIO community, yet the course based PBL delivery concept remained unchanged.

New PBL Model

Salti, Farhat, Abdel Niby, & Zabalawi (2021) presented a new 2+2 engineering technology program that is expected to be more flexible in the “what” and “how” students learn and hence, can adapt quickly to the exponential technological growth and the corresponding required knowledge and skills. The new program is also supposed to enhance the students’ graduate attributes to easily cope with the increasingly dynamic market needs and to further nurture the student-centered long-life learning skills. As far as the PBL approach is concerned, the authors argued that the course based PBL sets limited boundaries to the project as it must cover the course-specific technical course’s learning outcomes which reduces the possibility of introducing multidisciplinary PBL projects that are more likely to occur in real-life engineering workplaces. As such, in the newly suggested program, they adopted a more flexible PBL approach that is inspired from the model presented by Edström, K., and Kolmos, A. (2012).

The new model incorporates 3 PBL courses only, one per semester, in addition to the summative senior graduation PBL project which endures for one full academic year. Like the old PBL approach, the PBL journey of students starts in their fourth semester of study till graduation. However, unlike the previous model, in the new PBL model, the students are exposed to one PBL course per semester only to reduce the study load that is usually heavier than traditional courses due to the PBL self-learning component. In addition, the PBL courses are no longer course specific, but have general learning outcomes that allow the facilitators to create multi-disciplinary projects extracted from realistic life scenarios and consequently, allow students to apply their pre-acquired knowledge and skills as well as elements of the courses they are taking simultaneously with the project. This enables them to conceive, design, implement and operate their projects as per their passion and learning interests and accordingly, improve their motivation, creativity, and productivity.

New PBL Model & CDIO

Compared to the old PBL model, the new PBL model is supposed to improve the implementation of standards 1, 2, 3, 7 and 8 in engineering programs at the Australian University.

As for Standard 1: the context, the flexible learning outcomes of PBL courses allow facilitators to use realistic projects which are extracted from daily life engineering problems. Any new requirements in the development of product, process, system, and service lifecycle can be reflected in PBL projects in a smoother way. Typical examples are the sustainable, human-centric and resilience characteristics of industry 5.0.

Moving on to Standard 2: Learning Outcomes, and as per its corresponding self-assessment rubric in the CDIO syllabus, the highest score is achieved when "Internal and external groups regularly review and revise program learning outcomes and/or program goals based on changes in stakeholder needs" within the institution. The flexibility added by the new PBL approach allows an implicit and relatively prompt incorporation of new stakeholder needs (e.g., in the form of project requirements at the course level). If needed and if the implicit tests led to a success, the changes may be explicitly reflected on a larger scale, i.e., on the program learning outcomes as per the regular program revision cycle.

Moreover, regarding Standards 3 & 7: Integrated Curriculum and Learning Experience, the new PBL approach enables facilitators to use multidisciplinary projects to trigger the learning experience of students. This enriches the integration between the various technical disciplinary-related knowledge and skills as well as the development of interpersonal and intrapersonal skills within a learning work environment that is better emulating real life engineering workplaces.

Finally, although PBL by itself fundamentally serves the requirements of CDIO Standard 8: Active Learning, the learning in the new PBL approach is triggered by a project that is more likely a multidisciplinary project extracted from real life scenarios. This is expected to improve students' motivation as active learners and to further trigger their creativity as they would see themselves as young engineers who are conceiving, designing, implementing, and operating a solution that addresses a realistic engineering problem. This would result in creative solutions that satisfy students' ambitions and preferences while integrating the knowledge and skills from the pre-requisite courses, the simultaneous courses that they are taking with the project as well as new knowledge they self-learn to achieve the various goals of project.

CURRENT VS NEW PBL MODEL FLEXIBILITY

Quantitative Survey

A quantitative survey was conducted on experienced PBL facilitators at the Australian University to evaluate and compare from their perspective, the curriculum flexibility offered by the current PBL model, and the predicted flexibility of the newly suggested PBL model. The survey addresses the following main question: How PBL facilitators at the Australian University would perceive the curriculum flexibility added by the new PBL model compared to the currently implemented one?

It hence aims at validating the following main hypothesis: From the perspective of PBL facilitators at the Australian University, the new PBL model is expected to add more flexibility to the curriculum than the currently implemented one.

Table 1. Quantitative Survey Questions

Dimension	Part 2	Part 3
Learning Flexibility (What)	CM1: The current PBL course(s) that I am facilitating is(are) flexible in terms of "What" students are learning	NM1: I believe that the new PBL approach proposed in the new curriculum will provide more flexibility in terms of "What" students are learning.
Learning Flexibility (How)	CM2: The current PBL course(s) that I am facilitating is(are) flexible in terms of "How" students are learning.	NM2: I believe that the new PBL approach proposed in the new curriculum will provide more flexibility in terms of "How" students are learning.
Learning Outcomes Flexibility	CM3: I have flexible learning outcomes within the PBL course(s) that I currently facilitate.	NM3: I expect that the new PBL approach proposed in the new curriculum will address the flaws of the current PBL approach.
Serve Dynamic Industry	CM4: The current PBL course(s) that I facilitate has(have) outcomes that meet the dynamic nature of industry	NM4: Flexible learning outcomes incorporated in the new curriculum can serve the dynamic market needs.
Interdisciplinary Interactions	CM5: The current PBL course(s) that I facilitate promote(s) interdisciplinary interactions.	NM5: The new PBL approach proposed in the new curriculum will promote interdisciplinary interactions.
Overall Flexibility	CM6: Overall, the PBL course(s) that I facilitate add(s) flexibility to the program of study.	NM6: Overall, I expect that the new PBL approach proposed in the new curriculum will add flexibility to the program of study.

Study Methodology & Environment

The quantitative survey consisted of a three-part questionnaire supported by an explanatory video. The first part aimed at collecting demographics such as age, gender, and specialty of participants. After collecting the demographics, the participants were asked to watch a five-minute video that explains the new PBL model and presents its main differences with the current PBL model that they are practicing at the Australian University. The second and third parts consisted of 6 questions each which aim at assessing the flexibility of the current PBL model (CM1-CM6) and the new PBL model (NM1-NM6), all designed based on a Likert scale from 1 to 5 where “1” represents “Strongly Disagree”, “2” represents “Disagree”, “3” represents “Neutral”, “4” represents “Agree”, and “5” represents “Strongly Agree”. To each question is associated a flexibility dimension. Table 1 summarizes the questions and the corresponding flexibility dimensions.

A pilot study has been conducted prior to the distribution of the questionnaire to explore whether any question is not clear and to identify any areas of improvement. Three random PBL facilitators have been asked to fill in the survey and some comments have been raised and addressed. After the pilot study, an updated version of the questionnaire has been distributed to the whole population which consists of 51 PBL facilitators at the College of Engineering at the Australian University who have been facilitating PBL for at least 2 semesters. The data was collected towards the end of the Fall semester of the academic year 2022-2023 and a response rate of 58.8% has been achieved (i.e., 30 participants out of 51) with 30% of participants are from Electrical & Electronics Engineering, 30% from Mechanical Engineering, 26.7% from Petroleum Engineering, and 13.3% from Civil Engineering. Moreover, 20% of the participants are females and 80% males.

Results

Data has been analyzed using the SPSS 29.0.0.0 version. Frequency and descriptive tests were implemented to extract basic statistical values such as means, counts, and standard deviations. Figure 1 summarizes the obtained mean value for all questions classified by the evaluated flexibility dimension. The corresponding standard deviation values ranged between 0.8 and 1.3 which means that the responses were relatively consistent and that the mean value may be considered as a valid variable to extract conclusions from.

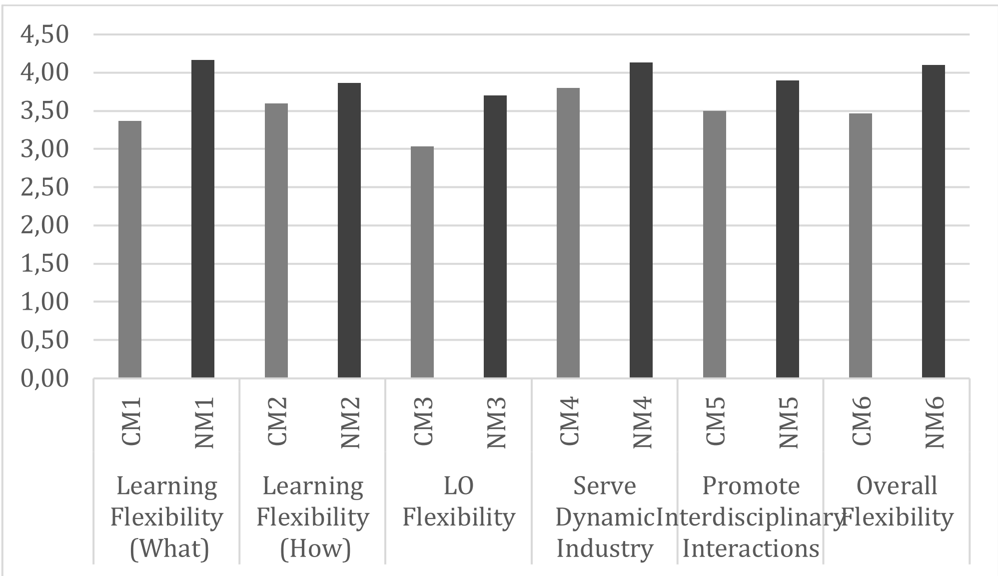

Figure 1. Quantitative Survey Results: Mean Scores

Figure 1 shows that the new PBL model scored mean values above 3.5 for all the studied flexibility dimensions which indicates that most of the AU PBL facilitators agree that the new PBL approach adds flexibility to all the studied flexibility dimensions. On the other hand, the highest mean (4.17) was obtained for “NM1: Learning Flexibility (What)” which indicates that most of PBL facilitators agree to strongly agree that the new PBL model adds more flexibility in terms of “what” students are learning. Moreover, the lowest mean (3.03) was obtained for “CM3: LO Flexibility” which indicates that PBL facilitators are not quite convinced that the current PBL courses have flexible learning outcomes. This is compatible with the stated hypothesis and the objectives of the new PBL approach (Salti, Farhat, Abdel Niby, & Zabalawi, 2021).

Moreover, to compare the new to the current PBL models in terms of flexibility from the perspective of PBL facilitators at AU, the “Normalized Flexibility Enhancement (NFE)” ratio is calculated for each of the studied six flexibility dimensions. It is calculated as the mean score of the current PBL model (CM) subtracted from the mean score of the same dimension in the new model (NM) then normalized to the highest mean difference as per equation (1) and (2).

$$FE_i = \frac{NM_i - CM_i}{max_i\{NM_i - CM_i\}}\% \quad (1)$$

Where

$$max_i\{NM_i - CM_i\} = NM_1 - CM_1 = 0.8 \quad (2)$$

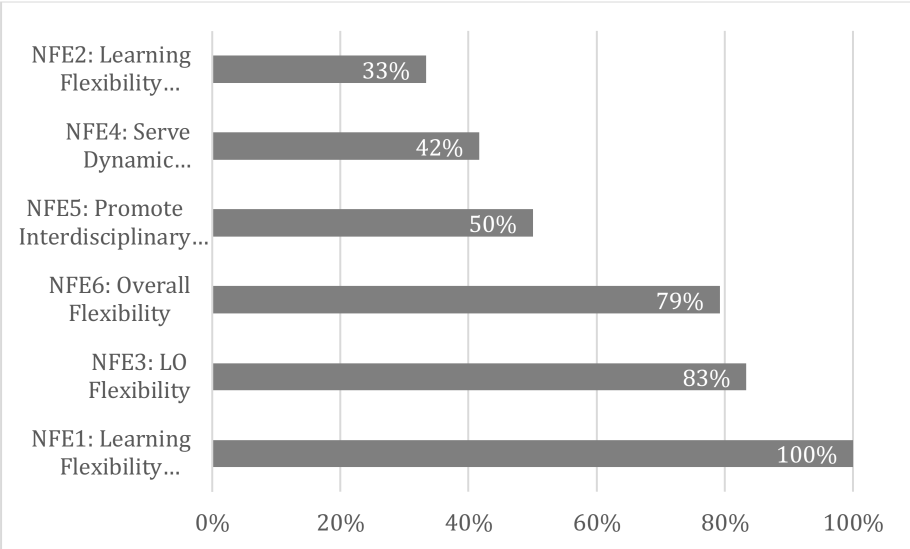

Figure 2. Quantitative Survey Results: Normalized Flexibility Enhancement Ratio

Figure 2 shows the sorted Normalized Flexibility Enhancement (NFE) ratio for all the studied flexibility dimensions. All the obtained values are positive which indicates that PBL facilitators at AU agree that the new PBL approach will enhance the flexibility at all the studied dimensions. Interestingly, the “Learning Flexibility (What)” dimension scored the highest NFE (100%) followed by the “LO Flexibility” (83%) and then “Overall Flexibility” (79%). This means that the PBL facilitators at AU are convinced that the new PBL approach will add more flexibility, when compared to the current PBL approach, to the knowledge component of the PBL courses and to their learning outcomes which will certainly reflect on the overall flexibility.

On the other hand, the lowest NFE score was obtained for the flexibility dimension related to “How” students learn which is expected since the PBL student-centered implementation approach would be almost the same in both scenarios and the PBL facilitators did not yet experience the new PBL model to consider the student motivation aspect that was discussed earlier. Surprisingly, although the new PBL approach is expected to promote interdisciplinary interactions and to better serve the dynamic nature of industry, PBL facilitators at AU are not very convinced that this would be the case if the new PBL approach is implemented. This may be linked to their unfamiliarity with the practical implementation techniques of the new PBL approach from one side and to their resilience to change from the other side.

Qualitative Survey

To unveil the pros & cons of the current vs the new PBL model from the perspective of AU PBL facilitators, a qualitative method is followed. It consists of a four-question interview that aims at discovering the flaws and strengths of both the current and the new PBL model as follows:

- What are the flaws of the current PBL approach regarding its limited flexibility?
- What are your thoughts with regards to the flexible learning outcomes offered by the new PBL approach?
- How do you think the new PBL approach will better serve the facilitator as well as the learner?
- What are the challenges that may face the implementation of the new PBL approach?

The interview questions were distributed via e-mail. Eleven PBL facilitators from the College of Engineering responded to the interview questions all through replying to the e-mail which increased the accuracy of the data collected. The NVivo12 qualitative research data analysis software has been used to analyze the interviews text and generate a frequency table. For the qualitative survey, the most experienced PBL facilitators were selected (3 to 7 years of experience).

Based on the design of the interview, the data was categorized into 4 categories: (1) Pros of current model, (2) Cons of current model, (3) Pros of new model, and (4) Cons of new model. Multi-level coding process was followed. The main core codes were selected based on the highest number of references. Only codes with at least three references were selected in the last layer of the coding process. To check whether the new model addresses the flow of the current model, the identified cons of each model were compared to the pros of the other one. Tables 2a and 2b show the cons of the current model vs. the pros of the new model and the pros of the current model vs. the cons of the new model respectively. In these tables, each line presents a code with its “reference” representing the identified keyword, its “frequency” representing the code’s repetition count in the interviews text, and its “percentage” representing the code’s occurrence percentage among all other identified codes.

As seen in Table 2a, the main disadvantage pointed by facilitators within the current PBL model is that it has a limitation in terms of topic versatility. On the contrary, looking at the advantages foreseen by the facilitators in the new model, many pros have been discussed. Among the most influencing factors, facilitators expect that the new model will bring its great benefit to the students with 7 references with this context. Also, positiveness is highlighted in the context of learning outcomes, experiences, and even added value which is expected to address the gap of topics limitations in the current model. The results obtained in the qualitative survey are hence coherent with the conclusion drawn from the quantitative one as facilitators seem to agree that the new model will be beneficial to the students and the PBL experience in general.

On the other hand, Table 2b shows that the main advantage of the current model from the perspective of PBL facilitators is that it has no major flaws whereas the main disadvantage of the new model is that it will be more challenging. Combining these observations with the numerous advantages of the new PBL model and the cons of the current model stated by the same facilitators is an indicator of a resilience to change. Hence, it is expected when facilitators get more familiar with the new model, this disadvantage will be overcome, and all the foreseen pros will bring its successful outcomes. This suggests that a sequence of professional development sessions and workshops are needed prior and during the implementation of the new PBL model as per CDIO standards 9 and 10 to overcome any resistance that may occur at the initial phase of implementation.

Table 2a. Frequency Table of Codes

Current Model Cons Reference	Frequency	Percentage	New Model Pros Reference	Frequency	Percentage
Limited Topics	3	21.43%	Benefits Students	7	19.44%
			Positive Outcomes	5	13.89%
			Positive Learning Experience	4	11.11%
			Good Project Experience	4	11.11%
			Added Value	3	8.33%

Table 2b. Frequency Table of Codes

Current Model Pros Reference	Frequency	Percentage	New Model Cons Reference	Frequency	Percentage
No Major Flaws	3	60%	More Challenging	3	60%

DISCUSSION & CONCLUSION

The engineering field is nowadays very dynamic due to the increased demands for modern life and new technologies that are emerging every day. This reflects on the engineering higher education sector which is required to produce engineers who are long-life learners from one side and are aware of the most recent technological trends and their development from the other side. Curriculum agility is foreseen to address the challenges. As such, higher education institutions started to introduce new teaching pedagogies and other strategies to add flexibility to their curricula. Project Based Learning (PBL) which is a relatively new teaching pedagogy is suggested as a flexibility degree of freedom in engineering curricula as learning is triggered by a real-life scenario project that is usually extracted from everyday engineering problems. However, the level of flexibility that PBL adds to an engineering curriculum depends on the way it is implemented.

This paper presented two PBL approaches, the course based PBL which is now being implemented at the College of Engineering at the Australian University in Kuwait and a new PBL model that is yet to be implemented. This was followed by illustrating the enhancements that the new PBL model is expected to add on the implementation of the CDIO standards at AU. Finally, the results of a quantitative and qualitative survey research are presented to draw conclusions on the flexibility degree added by both PBL models from the perspective of experienced PBL facilitators at AU. Whereas the quantitative survey addressed the flexibility offered by each of the two models, the pros & cons of these models were investigated using the qualitative method.

When comparing both models statistically, the main findings from the quantitative study revealed an indication that facilitators are somehow satisfied with the current model but also have better expectations from the new model. Moreover, using the "Normalized Flexibility Enhancement (NFE)" ratio, results showed that PBL facilitators at AU are convinced that the new PBL approach will add more flexibility, when compared to the current PBL approach, to the knowledge component of the PBL courses and to their learning outcomes which will certainly reflect on the overall flexibility. Moreover, the qualitative study uncovered promising results regarding what AU facilitators are expecting from the new PBL model such as bringing more benefit to students and positiveness in terms of learning outcomes and student experiences. While this optimism is forecasted by AU facilitators, they have expressed their fear that the new model may impose more challenges in its implementation which is expected to diminish once the new model gets into the implementation phase due to the learning curve theory. This suggests that the new PBL model needs to be clearly introduced to the facilitators to overcome any resistance that may occur at the initial phase of implementation.

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BIOGRAPHICAL INFORMATION

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SUSTAINABLE AIRCRAFT DESIGN IN ENGINEERING EDUCATION: CONCEIVE, DESIGN, IMPLEMENT, AND OPERATE VIRTUALLY

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ABSTRACT

In the Australian context, greater emphasis has been placed on capstone design projects to address research requirements associated with honours-level engineering degrees. This work highlights the implementation of CDIO for aeronautical engineering capstone projects. Two students in 2022 were offered a digital engineering CDIO-based capstone design project with sustainable aviation objectives as part of their thesis project. The case study highlights that many CDIO aspects can be successfully incorporated into a fourth-year engineering project for aeronautical engineering and why that succeeds. The use of digital simulation facilitates a cost-effective means by which engineered aerospace systems can be implemented, operated, and innovatively iterated by students for deeper understanding of flight.

KEYWORDS

Aircraft Design, Flight Testing, Capstone, Standards: 2, 3, 4, 5, 6, 7, 8, 11

INTRODUCTION

In all engineering education, and specifically in aeronautical/aerospace, there exists a need for imparting an increasingly complex core of technical knowledge, as well as the knowledge and skills that need be possessed for managing real systems and teams. The managing of systems and teams, necessarily, requires both functional knowledge, in addition to intrapersonal and interpersonal awareness. As the economy, and the engineering discipline, continues to grow more technically and organisationally complex, these two needs will have to be balanced by educational institutions. Whilst this balancing act maybe a cause for tension in engineering education (Crawley, 2001), the use of modern digital technology offers a solution. Significantly, authentic activities that mirror the real-world result in notably higher student engagement (Robinson, 2013). The simulation of real-world activities has been shown to facilitate students' understanding of the underlying concepts (Jimoyiannis & Komis, 2001). The use of aircraft engineering simulation software allows for the exploration of various concepts, both locally and remotely, without expending significant resources needed to envisage, evaluate, and iterate a design. Such software can allow for exploration of optimisation of requirements such as sustainability concepts, using local or remote computing resources.

Engineers must increasingly maintain an awareness of the environmental impact of technology (UNESCO, 2010). Design, prototyping, testing, and manufacture of complex machinery requires the use of natural resources and vast amounts of energy (EERE, 2022). Ironically, the exploration of engineered products that might assist in improving the sustainability of the aerospace or aviation industries, both in environmental and economic terms (Schneider, 2001), necessarily impose an ecological and monetary cost. Undergraduate programs can educate future engineers on matters of sustainability (Duarte et al., 2020). The requirement that engineering programs must educate students on environmental and sustainability matters is being highlighted by multiple organisations (NAE, 2004; Volkwein et al., 2004). The use of virtual prototyping (VP) has previously been highlighted as a form of 'sustainable engineering' (Papahristou & Bilalis, 2017) in so far as fewer resources are consumed in the prototyping of products. This virtualisation can be taken further, through the use of advanced flight simulation software, to allow for the digital operation of the final product.

The education of aerospace engineers, particularly those whose future work will involve the engineering of aircraft systems, poses a unique challenge. Though the complexity of all engineering disciplines has continued to increase, this is acutely true for aircraft design. In so far as the opportunities for the practice of engineering on aircraft have decreased, engineering science will necessarily increasingly come to dominate (Crawley, 2001). The CDIO (*Conceive-Design-Implement-Operate*) approach, which was a reaction to engineering science displacing engineering practice (Edström & Kolmos, 2014), grounds abstract engineering concepts in experience. For an upper-undergraduate level capstone project, this involves the immersion of the student[s] in every part of the lifecycle development of an engineered product (Miller & Bodeur, 2002). The *Design-Conceive* phase, during which students must learn to model and analyse various aspects of the product to be engineered, across the lifecycle of the product, is achievable for any given sub-system, but not the full aircraft. Further, within the constraints of a capstone project, the prohibitive costs and regulatory complexity make the *Implement* and *Operate* phases difficult. Within the *Implement* phase, experimental design is outside of the resources generally available. The *Operate* phase also faces challenges, not the least of which, particularly in Australia, is the complexity of integrating a component onto an aircraft. In considering the implementation of CDIO, all these challenges and opportunities, as well as the nuances of the existing University structures, must be carefully considered.

As with many engineering programs, both in Australia (Wild, 2022) and internationally (Halim et al., 2014; Todd et al., 1995), students at UNSW Canberra have the opportunity to undertake a design capstone course. The existing structure of design and capstone courses currently undertaken by undergraduates inside the School of Engineering and Information Technology (SEIT), emerged over four years ago from an approach far closer to problem/project-based learning (PBL), but has been able to extend towards CDIO with the advent of commercial-off-the-shelf simulation. The existing assessment structure is such that, with proper guidance from the supervisor and external design reviewers (i.e., industry experts), the student faces challenges like those experienced in professional engineering occupations. The student must submit interim engineering reports, engineering deliverable reports, and present an oral defence of their engineered solution, simulation, and prototyping before a panel of professionals (UNSW Canberra, 2022a, 2022b). The supervisor for each project, along with assisting technical advisors, and the panel of professionals, are all selected for a given project based upon their professional expertise in the design space. Opportunities for aircraft systems engineering within the capstone projects, particularly those focussed on iterative design amidst flight-test simulation, have recently been enhanced by upgrades to the University's flight simulation laboratory.

To examine this CDIO pedagogy in more depth, two students in 2022 were offered a more extensive digital engineering CDIO-based capstone design project with sustainable aviation objectives as part of their thesis project. It was hoped that this in-depth extension would document why the CDIO approach, as implemented, was working well and provide insight into wider implementation in the aeronautical engineering context. Hence, the credibility of this research is in both the underpinning four years of extant CDIO pedagogy for over 120 students, informed for improvement by the in-depth case study with two students.

The aim of this work is to demonstrate how traditional design, build and fly (DBF) CDIO PBL activities (Hansman, 2009) can be modernised with digital engineering. This facilitates meaningful aerospace engineering outcomes with minimal resources. An all-digital ecosystem can facilitate an aerospace CDIO capstone project, or with access to 3D printing and a suitable wind tunnel, practical extensions are possible. The implementation of CDIO for capstone engineering research projects continues previous work applying computational thinking to undergraduate capstone projects (Wild, 2022).

ADAPTING A CAPSTONE PROJECT COURSE

The general plan for a CDIO approach within the existing capstone project, and the actions required of the case study student[s], are here outlined. Initial consideration had been given to the application of the approach to a capstone project course based upon the engineering of RPAS (remotely piloted aerial systems). The engineering of RPAS has previously been put forth as suitable for engineering education (Maroney & Soban, 2018), for many of the same reasons previously highlighted, and with many of the same potential educational benefits. Thus, coupling RPAS with a virtual/digital CDIO approach provides equivalent educational opportunities. Students do create a 3D print and wind tunnel testing which is physically representative at scale to move beyond the pure digital realm. Virtualisation, and in particular virtual prototyping (VP), has the potential for improving outcomes in engineering education (Bhatt et al., 2009). The design of a system or sub-system for a crewed aircraft requires more multi-disciplinary thinking, going beyond mechanical considerations, and considering the human, social, and economic elements (Sadraey & Bertozzi, 2015).

Outline

The vast complexity of a modern aircraft, in terms of engineering and compliance, means that assigning the task of design, to an operational standard, was not viable for the capstone. The use of teams of students could, within a different program, conceivably allow for such a task. The existing structure of the capstone, which makes use of self-selection into an individual supervisor’s project, restricts the number of students that would be available. Future modification of the capstone project could resolve this issue. With the expectation of low student numbers, working across a relatively short period (one year), the system design task must focus on a single system, for one aircraft concept. Much consideration must be given to the aircraft, with a particular concern as to modification and sustainability matters. Any system selected should be modifiable to a particular end, through multiple potential schemata. In so far as this allows for each student to develop their own approach to engineering the system, it also requires that the student consider the “factors that set the context of the system goals” (Crawley et al., 2011). Viz., the other student[s] represents a competitor against whom any engineered solution is to be benchmarked.

The *Conceive-Design* phase consumes the majority of the first semester, and therefore the first course of the capstone. During this phase an initial review of existing solutions, both implemented and experimental, is expected. Development of the system is initially completed using traditional pen-and-paper calculations, prior to the use of computer-aided design tools. As the intention in the case study was for the design of an aircraft with improved sustainability credentials, the selected aircraft concept may differ substantially from those that the student[s] has much experience of from earlier aeronautical engineering courses. Therefore, simulation of an established model of the aircraft is necessary during this phase, so as to establish the boundaries of the work. This simulation may be completed in any suitable software that produces accurate aircraft output data. Progress is assessed throughout the process by the supervisor, expert presentation panels, and importantly student self-realisation when aspects don't work.

The *Implementation* phase is spilt across the end of the first semester, and the beginning of the second semester. The phase begins with the integration of the systems into the established model. As the integration is completed virtually, it is necessary to ensure the model is not modified, other than for that system. Testing utilising standard flight-testing methodologies is then completed. During this process, any modifications made are documented in a design document. As with traditional flight testing, and indeed the testing of any engineered system, simulation of the aircraft model produces vast amount of data. The data must be analysed to confirm the operation of the system, and the comparative performance. Progress is assessed throughout the process by the supervisor and is formally assessed, for course one in the first semester, through a *viva voce* and a submitted interim report.

The *Operate* phase occurs in the second semester, following the testing portion of the *Implementation* phase. Planning for operations, even within a simulated environment, requires the preparation of modified checklists, data extraction procedures, and suitable documentation. Use of the modified model by novice pilots, with particular focus on the implications of the new system, is then completed. Those operating the aircraft are required to provide formalised feedback, using a variety of industry standard tools. The use of more technical tools for the objective performance of the aircraft and system performance are supplemented by pilot evaluation tools, including the NASA TLX (Hart & Staveland, 1988) and Cooper-Harper rating scale (Cooper & Harper, 1969) and aeronatical engineering standards for flight test (*Flying qualities of piloted airplanes*, 1980). Progress during the *Operate* phase, as well as the testing portion of the *Implementation* phase, is assessed by the supervisor. The final assessment, for both the second course and the capstone, is through another *viva voce* and a final report.

Working with the CDIO Standards

This work was undertaken within the existing capstone framework. Thus, the approach must achieve the same outcomes, and to the same level. Furthermore, the approach must work within the Australian Qualification Framework (AQF), whilst incorporating CDIO.

Within the Australian Context

AQF is the national policy for regulated qualification in Australian education and training (AFQ Council, 2013). The revised framework published in 2012 is made up of 10 levels, from a high school diploma (Senior Secondary Certificate of Education) at level one to a doctorate at level 10. A standard three-year bachelor's degree is at level 7. A four-year degree may be at the AQF7 level or could qualify for AQF8 if considered a Bachelor Honours degree (AFQ Council, 2013). The requirement for AQF8 is a substantial research component in the 4th year, equivalent to the year extension offered to general science and other three-year programs where a student completes a research year undertaking a major capstone project with an associated thesis (AFQ Council, 2012). For engineering programs in Australia, the change to the revised AQF structure resulted in a significant increase in the time and effort associated with the capstone engineering project, bringing it in line with science honours programs to meet the AQF8 requirements. Historically, Australian engineering graduates of four-year degrees were only considered to have graduated with honours if they achieved a suitably high score. Under the revised AQF, all graduates must complete a substantial research component such that they meet the criteria to graduate with honours (AFQ Council, 2013). As such, under the revised AQF structure, the term honours, such as to "graduate with honours", no longer means meritorious achievement (AFQ Council, 2012).

Prior to the implementation of the AQF structure, engineering education research had already identified issues in engineering capstone courses (Rasul et al., 2015). Specific concerns included a lack of preparation, marking issues (such as supervisor bias), course assessment dimensions (the outcomes or the journey), and limited training and support for supervisors (Wild, 2022). The doubling of effort in many honours capstone courses to meet the AQF8 requirements, and the need to have all students complete a thesis, has likely only exacerbated these issues. As such, implementing a digital engineering solution with CDIO offers an ideal solution for aeronautical and aerospace engineering programs.

Within the Existing University Course Framework

CDIO Standards 2, 3, and 4, which address curriculum development, are well addressed within the capstone implementation. Standard 2, which regards learning outcomes, requires that there be precise and comprehensive outcomes for the skills, including personal and interpersonal skills, and disciplinary knowledge (Crawley et al., 2014). The present CDIO implementation aligns with the institutions mission, and the required proficiencies are set for all outcomes (UNSW Canberra, 2022a, 2022b). The overall curriculum integrates, over multiple years, the skills, processes and system building competences, thereby addressing Standard 3. The existing degree structure includes courses that provide scaffolding for understanding the practice of engineering, including the process and interpersonal skills, thereby addressing Standard 4.

The fifth and sixth CDIO Standard address the design-build experiences and workspaces that support hands-on learning. The existing curriculum for those progressing towards the capstone includes, among others, the *Aircraft and Systems Design 1 (ASD1)*, and *Aircraft and Systems Design 2 (ASD2)* courses. These courses use a design-implement experience, at a basic level in *ASD1*, and at an advanced level in *ASD2*. Throughout *ASD1* and *ASD2*, as well as multiple other courses and the capstone, learning and experience is conducted in specialist engineering workspace; including, the flight simulation laboratory.

Active learning (Standard 8), through active experiential learning methods, is employed through the degree program, including the capstone project. The use of design-build projects and simulated professional engineering practice engage students in thinking about new ideas, and require overt student response (Brodeur & Crawley, 2005). These forms of experiential learning, and especially simulated professional engineering practice, are enhanced by the chosen learning assessments (Standard 11). The assessment of a student's understanding of fundamental disciplinary knowledge is achieved prior to the capstone course, with further verification through review of submitted design documents. The use of *viva voce* as an end-of-course evaluation of learning, and the continuing assessment of progress by the supervisor, allows for the assessment of such things as personal and interpersonal skill, process, and system building skills.

The present implementation of a CDIO approach does not address all twelve CDIO Standards, or even the seven essential standards. However, the value of the CDIO Standards is not about any given standard, but rather the aggregate approach (Edström & Kolmos, 2014).

CASE STUDY

Two 4th year engineering students at UNSW Canberra were engaged to undertake a sustainable aviation engineering capstone project, based upon earlier research on box-wing technology (Somerville, 2019). After discussions it became clear that their prior and concurrent enrolment in the Aircraft Systems Design (ASD) courses in the aeronautical engineering program at UNSW Canberra facilitated a higher level of design and development. Given previous work had investigated aerodynamic characteristics and potential sustainability impacts, new work would be able to focus on practical and operational aspects. This facilitated the use of CDIO, where the supervisory team as the stakeholders had expressed an interest in the flight testing of a box-wing aircraft to evaluate the dynamics and control of the novel structure. The ability to digitally implement the aircraft design through PlaneMaker and operationally test in X-Plane provided an opportunity to implement flight-test engineering approaches, following the concept and design phases (Franklin et al., 2022).

UNSW Canberra has implemented a flight simulation laboratory for a decade, with a focus on flight safety. The current iteration makes use of modern technology, along with synthetic flight trainers, and twenty workstations with HOTAS flight controllers. The primary flight simulation software utilised in the lab is Laminar Research's X-Plane. X-Plane is a flight simulator engine that implements an actual aerodynamic model, blade element theory. That is, X-Plane makes use of "computational fluid dynamics", as opposed to a "physics engine", meaning that actual aerodynamic parameters are calculated to model the aircraft, accurately. The ability to display and log these parameters makes it ideal to use in basic laboratory activities (Somerville et al., 2022). Included with the X-Plane software is PlaneMaker, a package for the engineering and modelling of aircraft. This means that students can implement and operate any aircraft conceived and designed into X-Plane.

Applicable CDIO Syllabus

Looking at the CDIO syllabus, the digital engineering and flight testing of sustainable aerospace vehicles maps to a significant number of points. These are giving in Table 1.

Project Overview

Utilising the NASA Project Template from the CDIO Knowledge Library, the project overview is given below.

"1.1. Overall goal or purpose"
The project was implemented to design and test a box-wing aircraft for use in general aviation. This was for a team of engineering students working for a full year (two semesters). While aerodynamics of box-wing aircraft has been previously studied, stability and control research is not as mature; hence, the focus was on practical flight-test engineering of a previously

optimised design. This was facilitated by the X-Plane with PlaneMaker software (Franklin et al., 2022).

Table 1. Applicable CDIO Syllabus Items from Crawley et al. (2011)

2.1.1	Problem Identification and Formulation	3.2.5	Graphical Communications
2.1.2	Modelling	3.2.6	Oral Presentation
2.1.5	Solution and Recommendation	4.1.2	Impact of Engineering on Society and Environment
2.2.2	Survey of Literature	4.1.6	Visions of the Future
2.2.3	Experimental Inquiry	4.2.6	New Technology Development and Assessment
2.2.4	Hypothesis Test and Défense	4.3.4	System Engineering, Modelling and Interfaces
2.3.4	Trade-offs, Synergies, Judgment and Balance in Resolution	4.3.5	Development Project Management
2.4.5	Critical Thinking	4.4.1	The Design Process
2.4.8	Time and Resource Management	4.4.6	Design for Performance, Sustainability, Safety, etc
2.5.1	Ethics, Integrity and Social Responsibility	4.5.1	Designing a Sustainable Implementation Process
3.1.1	Working in teams	4.5.5	Test, Verification, Validation and Certification
3.1.3	Stakeholder Engagement	4.6.1	Designing and Optimizing Sustainable and Safe Operations
3.2.3	Written Communication	4.6.2	Training and Operations
3.2.4	Digital Communication		

"1.2. Societal context and relevance"
A box-wing aircraft offers considerable fuel savings over conventional aircraft planforms (Somerville et al., 2015). A study of the potential impact found that in the case that a large training aerodrome utilised a fleet of box-wing aircraft in place of conventional aircraft, the direct reduction in CO2 would be 700,000 kg, while lead emissions would be reduced by 135 kg, per year (Somerville et al., 2018).

"1.3. Integration (e.g., where project fits in a course, program, or curriculum)"
The project was an optional part of the Bachelor Honours capstone research project. All students are required to complete an individual project, where possible working collaboratively with other students on related projects. The students have completed three years of an undergraduate aeronautical engineering program, including flight mechanics, aerodynamics, flight dynamics and control, propulsion, as well as materials, structures, and other general mechanical engineering (thermodynamics and fluid mechanics etc). Importantly, students had participated in Aircraft System Design 1, and would be co-enrolled in Aircraft System Design 2. The ability to digitally design and flight test an aircraft is covered as part of Aircraft System Design. That knowledge base includes learning about flight test engineering including human factors, and covered tools such as the Cooper-Harper rating scale.

"1.4. Description (e.g., complexity, duration, group size and number, budget)"
The prior knowledge gained during the Aircraft System Design course[s] facilitates a high level of complexity, where students can utilise their skills to conceive and design a new aircraft with the aid of basic computational fluid dynamics tools (covered in their undergraduate courses), which can then be implemented and operated in a digital simulation. The project was a yearlong undertaking, facilitating the entire CDIO process. In the specific case, a pair of students worked together on the project, each tackling different approaches to flight control.

"1.5. Learning activities and tasks (brief summary)"
In general, students complete a capstone research project for the degree. In the aeronautical application here, the students digitally design, build, and fly a test vehicle. The sustainable nature of the project is to conceive and design a vehicle with reduced emissions, with the chosen technology that of a box-wing. Students were expected to take ownership of the minor

body of research and reflect this to the wider community via presentations and written submissions. The assessment tasks included:

- **Interim Report and Viva** to outline the scope and significance of the intended research, including initial design, in report form and with an oral defence.
- **Project Seminar** to present the final findings of the research project in oral form.
- **Research Summary** to present the final findings of the research project in written form.
- **Deliverables** to address the outcomes of the research project.

CONCLUSION

In the Australia context, a greater emphasis is being placed on capstone projects to address research requirements associated with honours level engineering degrees. The further requirement to educated engineers about both functional knowledge, and intrapersonal and interpersonal awareness, appears to be addressable by implementation of a CDIO approach, where four years of capstone design students have graduated with exposure to the process through simulation of their designs. The aim of this work has been to show the implementation of a digital engineering CDIO-based sustainable aeronautics capstone research project to better appreciate how CDIO is effective and how to further improve the capstone design subject. We have presented a case study of an aeronautical engineering capstone research project, undertaken by a team of two students at UNSW Canberra. Many improved CDIO approach characteristics were identified to improve fourth-year engineering design subjects or research projects for aeronautical engineering. The use of digital simulation has also proven to be a cost-effective means by which engineered aerospace systems can be implemented and operated.

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Keith Joiner was an Air Force aeronautical engineer, project manager and teacher for 30 years before joining UNSW to teach and research test and evaluation. As a Director-General he was awarded a Conspicuous Service Cross and for drawdown plans in Iraq a U.S. Meritorious Service Medal. His 1999 PhD was in reform of calculus education and he is actively researching classroom environments with collaborative learning, management and teaching of artificial intelligence, interoperability, cybersecurity, and advanced test techniques.

Timothy Lynar Tim's primary research focus is the application of machine learning to cyber security. Tim has a background in simulation, modelling, machine learning and distributed computing including cloud and IoT systems. Tim's current modelling efforts are pertaining to cyber security particularly to the epidemiology of Cyber security and, Modelling Complex Warfighting. Tim has a passion for innovation and was a Research staff member and Master inventor at IBM Research for 7.5 years in that time he led the intellectual property development team of the Australia Lab and submitted over 100 patent applications. Tim joined the University of New South Wales - Canberra in 2019 where he is researching and applying machine learning to complex problems.

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BRINGING REFLECTIVE WRITING TO THE ENGINEERING CLASSROOM

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ABSTRACT

Reflective writing in Engineering is still a relative novelty. Engineering education focuses on technologies and engineering methods, in short, how to do stuff. Students need guidance on evaluating "Is my approach a good approach?" The application and selection of engineering methods need to garner more attention. Through reflective writing assignments, we offer the students a chance to evaluate their choice of methods (both cognitively and intuitively), reflect on their feelings around success and failure, and explore strategies to deepen learning and support well-being. Traditional scientific methods have taught practitioners to remove themselves from the experiment, but this is only part of the truth: the observer affects the result and is affected by the result. Students reported discomfort when asked how they felt in these situations: no one had offered this kind of exploration to them previously. Our brief experiment with introducing reflective writing to the academic classroom suggests benefits such as deeper-reaching learning, growing self-awareness, and the ability to identify potential pitfalls before they evolve into crises.

KEYWORDS

reflective writing, emotional intelligence, visible learning, intuition, Body-Mind Centering, CDIO Standards 4,7,8,11

INTRODUCTION

Traditional styles of engineering/scientific writing and lab notebooks place heavy emphasis on objectivity. Even guidances such as refraining from using active voice and the pronouns "I" or "we" endeavor to do the impossible: to remove the observer from the course of the experimental events and the recording of experimental results. Such grasping for objectivity is rooted in fantasy. Others have spoken out on the pitfalls of the disconnection this desperate clutching to objectivity creates (Palmer, 1998) — disconnection from the world around us, from each other, and from our own selves.

The goal of objectivity is discovering knowledge about the world by eliminating personal biases, emotions, and false beliefs. This idea was pioneered by Francis Bacon and became essential to modern science. Knowledge should be obtained empirically through carefully constructed observations that support the scientific hypothesis.

Polanyi (1958) highlights that we believe more than we can prove and know more than we can say. All claims to knowledge rely on personal judgment. Researchers' commitment and interaction with the universe reveal knowledge to us. Polany's writing influenced Kuhn (1962), who objects to the existence of objective knowledge. Scientific truth is only based on observations but organized in paradigms supported by groups of researchers. Polany stresses the personal element of knowledge, and Kuhn the social.

We refrain from arguing the merits of objective versus personal knowledge. We focus on how students obtain and uncover their knowledge. Scientists and engineers rely on their personal experiences in their work, but may still strive to remove their biases.

History is dotted with world-renowned scientists who have openly chosen the non-conventional path: not excluding themselves from their subjects, following their intuitions and in doing so, making world-breaking discoveries. As an example, we need not look further than Barbara McClintock, 1983 Nobel Prize winner, and her relationship to her corn plants. McClintock received the Nobel prize for her work on the genetics of corn plants. When Evelyn Fox Keller interviewed Barbara McClintock about her work, she noted some of the unusual language McClintock used. Language such as having patience to "hear what the material has to say to you", openness to "let it come to you", and having "a feeling for the organism" (Keller, 1983). This language, one of feeling and acknowledgment of the connection between experimenter and the material, is not one that we are accustomed to hearing from the mouths of scientists. Nor is this the language (or the attitude cultivated to produce it) that is typically encouraged in students in academic halls.

As the old saying by Brewster (1882) tells us, *"What does his lucid explanation amount to but this, that in theory there is no difference between theory and practice, while in practice, there is?"*

Instead of perpetuating the myth of objectivity, we propose here a different view: a view that accepts the entanglement of the observer with the experiment, acknowledging it as a logical consequence of the interconnectedness of all things and embracing the value of this connection. We cultivate awareness of this connection in the student through reflective writing assignments, engaging not only the student's intellectual mind, but the intelligence that resides in every cell of their body.

Questions about the nature of the mind and its connection with the body have drawn the interest of humankind as far back as we know. Our own thoughts and motivations for this paper come from a sense of intelligence that resides within the whole body, a "distributed mind" if you will, not just the thinking mind. We draw our inspiration from the the Body-Mind Centering experiential learning approach, born out of the life-work of Bonnie Bainbridge-Cohen (Cohen, 2012). While its original application is to movement and related fields, the applicability of Body-Mind Centering reaches far beyond those fields and includes the academic halls inhabited by scientists and engineers. What might we discover as scientists and engineers if we draw on the intelligence of our whole body and welcome our intuitive senses as equally valuable allies to our thinking

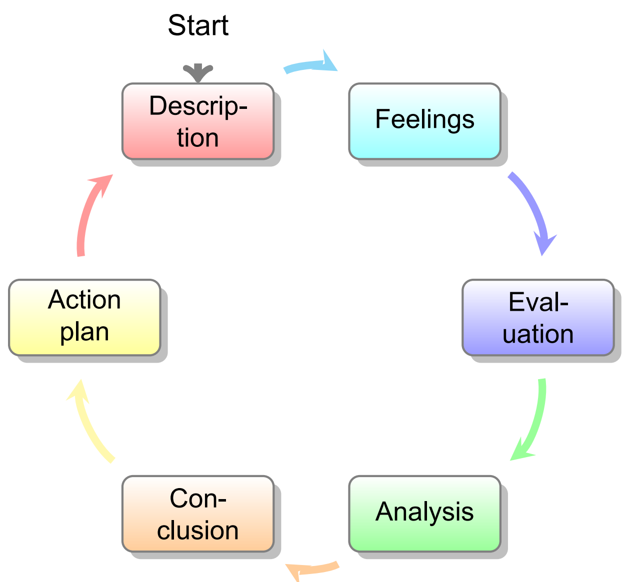

Figure 1. Gibb's reflective cycle (Gibbs, 1988)

mind? How might we be transformed if we allow our work to touch us personally? These are the questions we place at the center of our circle of shared inquiry and explore them here with the tool of reflective writing.

Dewey (1910) notes the value of reflection in learning. Later, Freire (1970) argues for moving from a banking model of education, where a teacher recites knowledge and students passively receive that knowledge. Instead, he highlights the need for a dialogue among learners. Palmer (1998) echoes this and offers the model of inter-connected learning with a community of learners gathered around a common subject of interest. Knowles (1975) points out that adult learners, and thus many students, have experiences that learning transforms. We hypothesize that reflective writing, combined with the integrated view of mind and body allows students (and instructors) access to greater creativity, innovation outside the box, the ability to identify potential pitfalls earlier, sensitivity that creates a deeper connection with the subject, healthier interpersonal relationships, and a deeper relationship to oneself.

BACKGROUND

Reflection is a crucial part of engineering processes. Today, agile methods like SCRUM are popular. Sommerville (2020, p. 53) writes: "Finally, it is a way for a team to reflect on how they can improve the way they work. Members discuss what has gone well, what has gone badly, and what improvements could be made."

We use Gibb's 1988 reflective cycle, displayed in Fig. 1 to describe the process. The process traditionally starts with a description of events that we reflect on. The practitioners repeatedly iterate these steps, answering the prompts: 1. Description — What has happened? 2. Feelings — What were you thinking and feeling during the events? 3. Evaluation — What was good and bad about this experience? 4. Analysis — What sense can you make out of the situation? 5. Conclusion — What else could you have done? 6. Action plan — if the same arose again, what would you do?

The reflective cycle should not end once started. By reflecting repeatedly, the learner evaluates the success of their action plan.

Huda Alrashidi has empirically evaluated the validity of reflection in computing education (Alrashidi et al., 2022; Alrashidi, Joy, & Ullmann, 2019). The specific criteria mentioned in their work were used to develop rubrics that will be mentioned later.

In the medical field, the concept is already a critical part of the process (Rolfe, Freshwater, & Jasper, 2001). In emergency medicine and surgery, it is standard practice to have a "morbidity and morality meeting" after any particularly stressful incidents including the death of the patient. Campbell discusses this necessity specifically as "a general move towards improved audit and quality control in surgical practice." which is the same intent in our investigation in Campbell (1988). The M&M, as they are colloquially called, is a closed meeting involving multiple levels of staffing including the participants. The intent is to create a confidential "safe space" to talk about what happened and how it affected everyone. These sessions give time for the medical professionals critical closure on such events while preparing for similar circumstances in the future. As the authors' previous paper on failure (Foley, Foley, & Kyas, 2022) suggests, engineering education needs to provide similar resources for their own stressful events and improvement.

APPROACH

The first author, M. Kyas, taught a class on Cyber-Physical systems to 40 third-year undergraduate computer science students in the Fall of 2022. A significant part of this course is implementing a rover that follows another rover at a set distance and avoids collisions. The students have not been exposed to measurement errors of sensors and imprecision of actuators. These probabilistic effects make systems challenging to debug. The challenges make many students doubt their abilities. Thus, the first author assigned weekly reflective writing tasks to make their learning visible and to turn their frustration into a productive learning element.

The second author, J. Foley, taught a similar 12-week class called Mechatronics 1 at the same time for 40 third-year undergraduate mechatronics students. Students were using the same parts kit to develop a mobile rover to follow a path on a test track as fast as possible in 6 weeks. The remaining 6 weeks were for students to design and develop a mechatronics project of their own choice. The author wanted to improve the student's retention of practical lab experiences by writing down the process and gaining closure on each section. This was previously done in a notably free-form manner with an assignment called "analysis" (comprising 35% of the student's grade). It asked the students to describe the problem, method, results, and conclusion every week. The author also implemented a partner "venting" session at the midway point where people would randomly pair off and share their frustrations in the class: students described their experience of this as stress-relieving and mini-celebrations. These processes were a start, but the instructor wanted more retention, so he consulted Ulrich, Eppinger, and Yang (2019) "Product Design and Development" which advised taking time to reflect on the process after each iteration. This was a moment of inspiration for him. The weekly notebook assignment rubric was assigned 4 out of 11 points toward reflective elements:

Reflection: Reflective writing (Alrashidi et al., 2019)

- You report a fact from experience and/or material, including your lab notebook entries. (specify which entry on what page)
- An analysis of the experience that you have described.
- You identify and analyze your thoughts and feelings.
- You provide reasons for your experience (you answer ‘why?’ questions)
- You link the experience that you reflect on to other experiences.
- You show alternatives
- You summarise what you have learned from the experience

The third author, M. Foley, brings to the table experience teaching in academic environments as well as the world of yoga, Qigong, and somatic movement. She is presently a mentor for the Daoist Flow Yoga Teacher Training at Triyoga, London. The course utilizes reflective writing through both open-ended assignments submitted for feedback and reflections that remain private to the student. The submitted reflections are evaluated based on the tone, the authenticity of the voice of the student, and evidence of whether the teachings are landing within the whole being of the student (as opposed to only in their thinking minds).

The shared inquiry into the potential value of reflective writing comes out of ongoing curiosities on the part of the three authors into innovative teaching and learning methods that challenge the rigidity of the vertical model prevalent in academic education (Foley et al., 2022).

FINDINGS

The Cyberphysical system teaching staff was able to defuse a tense situation in a student group by discovering that various members were discussing the lack of participation by certain members in their notebooks. A similar event occurred in Mechatronics 1 when a student became fed up with a particular member and decided to leave the team. That person then moved to another team without formally informing any of the teaching staff, which was needed to make sure group assignment credit was appropriately assigned. The staff discovered the issue when reading the entry of that student talking about how frustrated they were and considered leaving. This example shows the reflective exercise’s ability to identify and anticipate potential trouble in teams, which gives instructors a choice: let them continue down the rocky path or steer them to a smoother path? We hold that there is no right answer and the decision ultimately lies with the students themselves. The role of the teacher is to encourage awareness cultivation and hold space, as we describe in our previous work on failure in Foley et al. (2022). “They aren’t just going to tell us what to do. I have to decide.” In this instance, simply reading the student’s views on things gave deep insights into team interaction in a different method than internal team-rating surveys and the Meyers-Briggs personality test.

Non-native English-speaking students had much more trouble than expected with writing reflectively. This may have been due to the language obstacles as the instructor was most fluent in English and the students in Icelandic, French, and German. Further analysis possibly considering culture is worth further study. J. Foley's current investigation is now allowing reflective elements to be in the student's native language due to the availability of teaching assistants.

Some miscellaneous qualitative elements that Kyas and J. Foley noticed in their courses after adding reflective elements:

- Students seemed to be growing in awareness about the learning process
- General increased awareness with learning going deeper than just the brain.
- More engaged and engaging questions to instructors
- Students demonstrated deeper access to inner wisdom enabling them to answer their questions after reflecting: this may have been similar to the familiar concept of Rubber Duck debugging where one explains their problem and reasoning to a small toy.
- Many students seemed uncomfortable with writing reflections, particularly lacking emotional and sensing vocabulary (this improved by the end of the semester).
- Apparent disharmony between the body and the mind: overemphasis on the processes of the ”intellectual mind” while unconscious of the insights offered by the ”distributed mind” (the intelligence that lives within each cell of the body).
- Students often did not point in their reflective writing where the event could be found in the notebook. This may be due to a lack of notes taken during the event itself or indicate a need for a closer connection between past experiences and present-moment thoughts and feelings. Strengthening the connection should lead to designing better experiments.
- Vented frustrations: students seemed less stressed than in previous terms with similar workloads.

We freely admit that these results are preliminary and anecdotal and by no means objective evidence. Following our inquiry, we share here our present-moment thoughts, feelings, and intuitions in a similar reflective writing style that we ask of our students.

DISCUSSION

Based upon the benefits seen from the 2022 integration of reflective writing, J. Foley has implemented reflection in his EngineeringX course (12+3 weeks 6ECTS) in Spring of 2023, at the time of writing of this paper; instructions and evaluations were open and non-specific which resulted in the need to have a single evaluator to be consistent. The number of students has now grown large enough that a more explicit breakdown of the grading rubric's point values was given to the students to speed evaluation and feedback. Conveniently, Ulrich et al. (2019) explicitly states the need for reflection in processes, so the main assignment's guidance states: “Reflections: As mentioned in the textbook's discussion of the various processes it uses, it is very important to reflect on how things went and how they can improve. We also care about

Reflection: Report Reference: Alrashidi et al. (2019) You report a fact from experience and/or material related to your notebook entries. (Important: specify which entry on what page)
Reflection: Why? An analysis of the experience that you have described. You provide reasons for your experience (you answer 'why?' questions)
Reflection: Emotions and Intuition You identify and analyze your thoughts and feelings. Hint: "I feel …" probably should be in there somewhere. You link the experience that you reflect on to other experiences. Did you get "gut feelings" about various parts of the work?
Reflection: Closure You show alternatives: scenarios, choices, etc. You summarise what you have learned from the experience and how it has changed you.

Table 1. EngineeringX 2023 notebook reflection rubric: each section was 1 out of 12 points with three evaluation levels at Outstanding (1 point), Acceptable (0.5 points), and Unacceptable (0 points)

how you feel about the experience and what changes you see in yourself. Reflection must be done sometime after the event/analysis in question and needs to specifically point at which pages and data are relevant. Generally, this is around a paragraph or half page of text. See the rubric for details." This came about to speed grading and maintain consistency when dividing the feedback and grades returned to the students. A course of 122 students can now be have reflections evaluated by 4 teaching assistants in approximately 5 minutes per notebook which we found to be a very acceptable workload. The rubric used for this assignment as of the time of this writing is stated in Table 1.

Reflective writing is a frequently utilized tool within the world of yoga, movement, and mindfulness. Drawing on her own experience, Markéta interestingly notes she herself shies away from this technique due to discomfort. Self-reflecting, she wonders how her academic background may have contributed to this discomfort. Free-writing challenges Markéta's perception of writing as always needing to be coherent, organized, and logical — qualities that were impressed upon her as part of her academic education.

Markéta's experience is not singular. Engineering students are often caught in this challenging cycle of perfectionism when it comes to both assignments and related notes. A question often heard by instructors is: "Is it better for me to write things down as they are happening (but in a messy way) or write everything down later when I have time to organize and consider?" When left to their own devices, students frequently default to the latter — waiting until after the experiment to write in their notebooks — perhaps out of fear of getting a low notebook grade. One of the goals of the reflective writing assignment is to gently begin to wear away at the block that perfectionism has placed upon the path of discovery.

We propose that ultimately there is a need for both: writing down perceptions as they emerge and organizing the notes later, as part of the reflection process on what just took place. In the moment that the experiment is unfolding, the experimenter has the possibility to experience the event through the intelligence of the whole body. The life-work of Bonnie Bainbridge Cohen, Body-Mind Centering, offers that intelligence is present within each cell of the body, not just within the thinking mind (Cohen, 2012). When we become sensitive to perceiving this intelligence in the moment the experiment is taking place, we allow ourselves to draw on the full potential of our being. We access our own creative potential more fully and move beyond our conditioned, habitual ways of thinking and action (Hartley, 1995, Introduction). Learning becomes an integrated dance between the mind and the body. Lab notebook use during experiments and reflective writing assignments that bring awareness to the language of the body share the same goal: of involving the entirety of the being in the experimental process, accessing the ”distributed mind” within each cell of the body and integrating it with the cognitive, analytical process of the intellectual or thinking mind we are likely more familiar with from our own years within the academic walls.

In post-event analysis, reflection hopes to help us make sense of the experience we just had, to learn from it, and to contemplate the “why”. “Why did I pick up this particular book?” Logic may tell us to perform the experiment in a certain way, but maybe something is guiding us in a different direction. We pause, feel into our bodies and minds, and make a decision on how to move forward from an integrated state. Taking time to reflect, we hope will allow students to build sensitivity to the intelligence beyond their thinking mind while still being able to justify critical choices.

CONCLUSION

Reflective elements need to be considered when implementing CDIO processes at each phase as per the standard in (CDIO, 2020). As engineering students begin their learning, they need to assess (and re-assess along the way) if they are on the right path and what is/isn’t working (Standard 4 “Introduction to Engineering”). The subjective and communication-rich nature of making connections in the reflective elements build personal and interpersonal skills as described in Standard 7 “Integrated Learning Experiences”. Reflective journaling, when shared with the instructor, provides huge feedback from students about what they are learning. This is needed for Standard 8 “Active Learning”. Standard 11 “Learning Assessment” specifically states that one method is that of “student reflections, journals, portfolios, and peer and self-assessment”.

Reflective writing invites students into an authentic experience of themselves and their work. It is a tool that offers access to the intelligence of the whole being, not just the thinking mind, with value to both student and teacher. The teacher receives frequent feedback and can evaluate how the teachings are landing for the students, identifying areas that warrant further exploration. The combined value for both student and teacher is the ability to spot potential problems, points of confusion, and risks at earlier stages, enabling both to follow the ancient wisdom of the Tao Te Ching (Lao-Tzu, 1992, Chapter 64): to “prevent trouble before it arises”.

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BIOGRAPHICAL INFORMATION

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Markéta Foley received B.S. in Biology and B.S. in Chemical Engineering from Massachusetts Institute of Technology (Cambridge, USA) in 2000. After 7 years of putting her engineering skills into hands-on practice within the pharmaceutical industry, she returned to the academic teaching environment (first at MIT, USA, and later at Reykjavík University, Iceland). Here she spent another 7 years designing and teaching hands-on courses for both undergraduate students as well as industry professionals on topics ranging from molecular biology to fermentation and cell culture systems. Most recently, Markéta splits her time between independent consulting in the fields of toxicology, nutrition, and food safety and teaching movement and mindfulness as a certified yoga and Qigong instructor. Learn more about Markéta at http://www.marketafoley.com/.

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CREATING AND DEPLOYING AN ELECTRONIC ENGINEERING MASTER PROGRAM BASED ON CDIO FRAMEWORK

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ABSTRACT

Electronic engineering is an indispensable major for development in the Industry 4.0 era. The demand for human resources in this industry is increasing to meet the progressive requirements in smart systems for not only the world but also Vietnam. The graduate level of Electronic Engineering has been playing an important role in creating highly qualified human resources to meet the creative requirements in this Industry 4.0 era. Faculty of Electrical and Electronic Engineering (FEEE), Duy Tan University (DTU) has been developed and deploying a master's degree education program in electronic engineering based on the requirements of meeting human resources for Industry 4.0. At the same time, to ensure the effectiveness, we have built this education program based on the CDIO framework with its outcomes that closely follow the output standards of CDIO. This curriculum consists of 45 credits for 3 semesters with 12 courses that help learners to have the ability to conceive, design, implement and evaluate project results and/or products in the field of electronic engineering. These works are very necessary in doing research, developing, manufacturing smart systems, and operating in industrial production line which must consider the impact of engineering solutions in global, economic, environmental, safe, sustainable and societal contexts. In addition, the results of student's thesis are requested to present at the scientific conference of Duy Tan university to show their contribution. To evaluate the effectiveness of the training program implemented at Duy Tan University, in addition to assess its outcomes, we also base on the CDIO framework evaluation criteria, especially the evaluation of employers. The evaluation results have shown that the training program meets the requirements of human resource training for Industry 4.0.

KEYWORDS

CDIO framework, Industrial 4.0, Electronic Engineering, Master Degree, Education Program, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12.

INTRODUCTION

The Industry 4.0 concept was introduced in 2011 in Germany to enhance traditional industries' competition. It quickly became a strategic program in many developed countries, including the US, France, Korea, and China. Industry 4.0 has since spread worldwide, driven by significant developments in AI, intelligent machines, VR systems, 3D printing, IoT, biotechnology, and nanotechnology. This revolution is considered the most significant step forward since the advent of computers and the Internet. Combining big data analytics, cloud computing, and IoT will drive innovative development, and AI and cybernetics will enable remote control and faster, more accurate interaction. Industry 4.0 could fundamentally change the way people live, work, and interact with each other, promoting labor productivity, raising income levels, and improving quality of life.

However, the article (Erik Brynjolfsson & Andrew McAfee, 2014) has shown that this revolution could bring about greater inequality, especially the potential to disrupt the labor market. Many traditional business models in different fields are in danger of being overturned when automated lines and robots replace too many jobs done by humans. A report at the World Economic Forum shows that companies expect to restructure their workforces in response to new technologies. In particular, surveyed companies indicated that they are also looking to transform components in their value chain (55%), further automate, reduce existing workforce (43%) or workforce expansion as a result of deeper technology integration (34%), and expanding use of contractors for specialized jobs (41%). A similar study by the International Labor Organization also predicts that, in the next two decades, about 56% of low-skilled workers in five Southeast Asian countries, including Vietnam, are at risk of losing their jobs to robots (International Labour Office, 2018). More specifically, 86% of workers in the textile industry and 75% of workers in the electrical-electronic industry in Vietnam are at risk of losing their jobs due to automation (Jae-Hee Chang & Phu Huynh, 2016). Many studies at https://www.skillsdevelopmentscotland.co.uk/ have shown that the workforce is low- or medium-skill, working in low-productivity, low-wage jobs, with poor working conditions (e.g., assembly line workers, manual laborers, etc.) will be the most affected.

Industrial 4.0 raises concerns about unemployment as machines take on more tasks, but some researchers argue that reducing total employment is unlikely. Hyper-automation and hyper-connectivity can enhance productivity in existing jobs and create demand for new ones. Developed countries with a higher-quality workforce are expected to see declining unemployment rates and fewer workers in vulnerable sectors. However, high-quality jobs require a more educated workforce with advanced skill sets, challenging many developing countries like Vietnam. Education 4.0 is the future of general and higher education, emphasizing learner-centered, peer-to-peer, and project-based learning, flexibility in time and place, and real-world experience. Catching up with this educational trend will ensure quality human resources for the future. Accordingly, Duy Tan University is implementing the Education 4.0 model, becoming a leader in education reform in Vietnam (Truong V Truong et al., 2019) (Binh D Ha, 2019). The Faculty of Electrical and Electronic Engineering at DTU has developed a master's degree program in electronic engineering to meet human resource requirements for Industry 4.0.

ELECTRONIC ENGINEERING MASTER PROGRAM BASED ON CDIO FRAMEWORK DESCRIPTIONS

In this section, we will detail the application of the CDIO framework in the master's program in electronic engineering at FEEE. By sticking to CDIO standards 3.0 (Malmqvist et al., 2020), we build the program according to 12 standards, specifically as follows.

Standard 1: The Context

The Electronic Engineering (EE) master program at DTU serves the socio-economic needs of Central and Highlands Vietnam in the context of Industry 4.0. It is offered in traditional lecture and laboratory formats, occasionally with evening courses. E-learning resources are widely used in a blended mode to support the program, built based on the CDIO framework with 45 credits and 12 courses. Students complete a graduation project, and internships are optional. The program is designed for completion within 1.5 years, and its outcomes closely follow the standards of CDIO. The Program Educational Objectives (PEO) of the program are focused on career and professional achievements for graduates are as follows:

- PEO 1. Excel in individual and teamwork efforts for the development of electronic engineering solutions for local and global problems.
- PEO 2. Become successfully employed in the electronic engineering industry or related areas.
- PEO 3. Expand knowledge and capabilities through continuing education or advanced graduate study or other life-long learning experiences.
- PEO 4. Serve their communities either locally, nationally, or globally.

Standard 2: Leaning Outcomes

The EE master program at DTU's FEEE utilizes the EAC criteria of Learning Outcomes (LOs) to define specific statements that outline the knowledge and skills students should acquire by graduation from the program.The LOs of this program are as follows:

- LO 1. an ability to identify, formulate, and solve complex engineering problems by applying principles of electronic engineering, science, and mathematics.
- LO 2. an ability to apply electronic engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors.
- LO 3. an ability to communicate effectively with a range of audiences.
- LO 4. an ability to recognize ethical and professional responsibilities in electronic engineering situations and make informed judgments, which must consider the impact of electronic engineering solutions in global, economic, environmental, and societal contexts.
- LO 5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives.
- LO 6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use electronic engineering judgment to draw conclusions.
- LO 7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

Based on the LOs, more detailed Performance Indicators (PIs) were identified in Table 1.

Table 1. Learning Outcomes and corresponding Performance Indicators

Learning Outcome	Performance Indicator
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of electronic engineering, science, and mathematics	1.1 Ability to identify a complex engineering problem by using scientific principles.
	1.2 Ability to develop a hardware/software/math model for a complex engineering problem.
	1.3 Ability to solve a complex engineering problem using mathematics, science and/or electronic engineering principles.
	1.4 Ability to assess the performance of a solution to a complex engineering problem.

2. an ability to apply electronic engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors	2.1 Ability to recognize and distinguish important real-world constraints for a particular design or design component.
	2.2 Ability to translate practical quantitative constraints to appropriate design parameters.
	2.3 Ability to implement a design and verify that it meets the specified constraints.
3. an ability to communicate effectively with a range of audiences	3.1 Ability to use effective oral and body language with various audiences.
	3.2 Ability to prepare a well-planned and well-organized oral presentation or written report for various audiences.
	3.3 Ability to use effective electronic communication.
4. an ability to recognize ethical and professional responsibilities in electronic engineering situations and make informed judgments, which must consider the impact of electronic engineering solutions in global, economic, environmental, and societal contexts	4.1 Ability to describe ethical and professional responsibilities in the job.
	4.2 Ability to evaluate the ethical dimensions of a problem in the discipline.
	4.3 Ability to realize social values as well as environmental, economic and global impacts of an engineering design to make informed decisions or judgments.
	4.4 Ability to identify global, economic, environmental, and societal trends in related industries.
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives	5.1 Ability to perform individual tasks in a timely manner in conjunction with the team plans and schedules.
	5.2 Ability to integrate input from team members and to make decisions that meet predefined criteria and planned tasks.
	5.3 Ability to create an environment for team members to effectively participate and collaborate in team activities to meet objectives.
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions	6.1 Ability to set up an experiment using readily-available components, tools, and test equipment for the right design parameter measurement.
	6.2 Ability to find errors and adjust experimental data and setups.
	6.3 Ability to analyze and interpret experimental data, features, and outcomes.
	6.4 Ability to use engineering judgment for the purpose of modeling, prediction, or conclusion.
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies	7.1 Ability to identify relevant information and additional knowledge for a certain design solution.
	7.2 Ability to select modern and appropriate tools and techniques for a specific engineering task and to compare results from alternative approaches.

	7.3 Ability to independently select the right learning strategy for a certain project or study.

Standard 3: Integrated Curriculum

The EE master program requires the completion of 45 credit hours, which can be completed in 3 semesters or 1.5 academic years. The curriculum breaks down the courses into three categories of (1) General Education (GE) courses, (2) Fundamental (F) courses, and (3) and Advanced (A) Engineering courses as Table 2. The courses developed in the approach of CDIO 3.0 allows us to build and practice a set of necessary skills for learners, ensuring to meet new requirements in Industry. 4.0. Our target audience is quite diverse, from recent electrical and electronic engineering graduates, technical staff at enterprises, or researchers and teaching assistants at universities.

Table 2. Curriculum of Electronic Engineering

Course (Department, Number, Title)		**Course is Required, Elective or a Selected Elective.**	**Subject Area (Credit Hours)**		
			General Education	**Fundamental**	**Advanced**
PHY 550	Philosophy	R	3		
PHY 600	Scientific Research Methods	R	2		
CR 651	Advanced Computer Architecture	R		3	
EE 603	Information and Coding Theory	R		3	
EE 608	Random Signal Processing	R		3	
CR 686	VLSI Design	R		3	
EE 684	Digital Communications	R		3	
EE 682	Wireless Communications	E			3
CS 677	Encryption and Network Security	E			3
EE 702	Analog IC Design	E			3
EE 743	Fast Logic Technique	E			3
CS 715	Image Processing and Multimedia Technique	E			3
EE 723	Microwave Circuits	E			3
EE 725	Optimization Methods and Applications	E			3
EE 735	Mobile Communications	E			3
CR 733	Embedded System Design	E			3
EE 754	DSP Designs and Applications	E			3
EE 745	CDIO Project 1	SE			1
EE 746	CDIO Project 2	SE			1
EE 747	CDIO Project 3	SE			1
EE 749	Graduation Thesis	R			15

Table 3 describes the PIs covered by the subject combinations. It is not challenging to see that almost subjects complement the master student's Cognitive Analytics Abilities and Complex Problem Solving Skills, namely Cognitive Flexibility, Creativity, Logical Reasoning, Problem Sensitivity, Mathematical Reasoning, and Visualization (LO 1). Meanwhile, the subjects PHY 550, PHY 600, CR 651, EE 684, EE 686, EE 725, EE 745, and EE 749 help learners perfect Resource Management Skills, such as Managing financial resources & material resources, People management, Time management (LO 2). Some subjects are implemented in the form of discussion, presentation, and information exchange for students to achieve Content Skills (Oral expression, Reading comprehension, Written expression, and Social Skills (Persuasion) (LO 3). We cover ethical and professional responsibilities in EE situations in subjects PHI 550, EE 686, EE 745, and especially in EE 749 - Graduation Thesis (LO 4). Teamwork and leadership ability allows learners to gain Social Skills in Coordinating with others, Negotiation, and Training & teaching others (LO 5). The subjects CR 651, EE 754, EE 745, and EE 749 ensure Technical Skills such as Equipment maintenance, Programming, and Troubleshooting; and the ability to work with data such as analyzing data and information obtained from machines, understanding visual data output (LO 6). Finally, we must emphasize that students practice skills to choose appropriate learning methods and keep the lifelong learning mindset in mind (LO 7).

We built three CDIO projects to summarize the knowledge of the learning process before implementing the graduation thesis, including circuit design and fabrication (CDIO Project 1), optimal circuit design (CDIO Project 2), and wireless network design (CDIO Project 3). CDIO Project 1 draws on knowledge from EE 743, EE 723, CR 733, and EE 754, while CDIO Project 2 is supported by knowledge from CR 651, EE 684, EE 725, and CR 686. Similarly, CDIO Project 3 is supported by knowledge from EE 603, EE 682, EE 735, and EE 608. These areas of knowledge are suitable for meeting practical requirements in the Central and Highlands regions of Vietnam. Moreover, the program aims to instill the spirit and skills of CDIO in its students, which will contribute to improving the quality of their output.

Students can choose one of two directions to implement the research or application-oriented CDIO project. For research orientation, the outcome of the course is usually an academic paper, suitable for those who wish to continue their higher level of study or work as a senior technical advisor. We often create an online forum monthly moderated by experienced engineers and educators so students can discuss CDIO-related topics and share their experiences, and expand networking opportunities. For application orientation, the output is usually a technical report or a complete prototype design. This orientation is often chosen by students from the business that we refer to as "Kinesthetic learners." They always have technical issues that need to be solved. We provide hands-on activities for them, such as lab work, advanced simulation, and prototyping, combined with self-study hours from online resources.

Table 3. Mapping of essential Courses of EE program and Performance Indicators (PIs)

PIs	Courses Alignment to Performance Indicators (PIs)											
	PHI 550	PHI 600	CR 651	EE 603	EE 608	EE 684	EE 686	EE 723	EE 725	EE 754	EE 745	EE 749
1.1		X	X	X	X				X	X	X	X
1.2		X			X		X	X	X		X	X
1.3		X		X		X			X	X	X	X
1.4		X							X		X	X

2.1	X	X					X		X		X	X
2.2			X			X	X				X	X
2.3			X			X	X				X	X
3.1		X						X			X	X
3.2		X						X			X	X
3.3		X						X			X	X
4.1	X							X			X	X
4.2	X							X			X	X
4.3	X							X			X	X
4.4		X						X			X	X
5.1							X	X			X	
5.2											X	
5.3							X				X	
6.1			X				X			X	X	X
6.2			X								X	X
6.3			X							X	X	X
6.4			X								X	X
7.1									X			X
7.2						X			X			X
7.3							X					X

Standard 4: Introduction to Engineering

The EE master program at our institution emphasizes the importance of catering to diverse learners. This is achieved by ensuring that students have a solid understanding of EE concepts and standards, enabling them to easily absorb advanced knowledge. The program framework is designed to outline the tasks and responsibilities of an engineering master, as well as the use of disciplinary knowledge to execute these tasks. To increase student interest and motivation, we allocate 1 to 3 hours in each subject to provide an overview of the subject matter. This includes exciting and hot topics such as quantum computers, 5G and beyond-5G networks, chip design, and encryption techniques. Throughout the program, students engage in electronic design exercises and complex problem-solving tasks, both individually and in teams. The courses also include personal and interpersonal knowledge, skills, and attitudes that are essential for students at the start of the program, to prepare them for more advanced product, process, system, and service-building experiences.

Standard 5: Design-Implement Experiences

The EE master program has four courses that provide the integrating experience that draws from diverse curriculum elements and helps develop student competence by focusing on technical and non-technical skills in CDIO. Those four courses are CDIO Project 1, 2, 3, and Graduation Project, which are designed to provide practical and rigorous training in Interdisciplinary Projects, Problem-Solving Methodologies, Team-Building Skills, and Oral, Graphical and Written Communication Skills. These Design-Implement experiences help prepare students for engineering practices; awareness of engineering standards, consideration of ethics and its effect on society; and designing procedures based on real-world constraints. This process can be seen in CDIO Project 1: circuit designs are set up with industry-standard design tools such as Altium or Cadence, which are optimized for performance and cost. Next, the test benches are designed to ensure their design meets the functional and performance requirements. In-house and online discussions with experts are implemented to optimize the design before fabricating the circuit. Finally, testing and verification are implemented to evaluate the prototype.

Standard 6: Engineering Learning Workspaces

The learning environment at DTU provides learners with tools and facilities such as Libraries, the Internet, and labs to easily access learning resources, valuable opportunities, and experiences. Precisely, the learning environment parallels two real and virtual learning environments. In particular, the real learning environment helps students get closer to reality, while the virtual environment forms new experiences, stimulating learners to innovate and create. The learning environment also has a system of FabLab manufacturing laboratories equipped with various machine tools such as 3D printers, CNC machines, and electronic control devices... for students to make and test the prototypes, as shown in Figure 2. In particular, at DTU FabLab, there is a course called "How you can make (almost) anything" built in the direction of CDIO, providing the necessary knowledge and skills to form an idea to realize an actual product and do a scientific research project process. The Course Learning Outcomes (CLO) of this course are also very suitable and complement the EE master program, which is:

- CLO 1. Proficiently use equipment and software for the ideation, design, and manufacture of products.
- CLO 2. Proficient in scientific research methods.
- CLO 3. Ability to evaluate aspects of an idea or solution.
- CLO 4. Improve logical thinking capacity, teamwork skills, and communication skills.

Figure 2. Creative workspace at DTU FabLab

We continue to specifically present Engineering Learning Workspaces at FEEE, DTU as follows:
Laboratories: Besides the natural science and the computer labs being jointly used by faculties in the Division of Technology & Sciences (DTS), the EE program operates five major laboratories: (1) Basic Electronic Laboratory (as Figure 3), (2) Logical Controller Laboratory, (3) Processor/Microcontroller Laboratory, (4) Electrical Machinery Laboratory, and (5) Advanced Electronics-Telecommunication Laboratory. These laboratories are open for use to students under the guidance of laboratory technicians. The working hours of these laboratories

are from 7:00 AM to 11:00 AM, from 1:00 PM to 5:00 PM during weekdays, and from 7:00 AM to 11:00 AM on Saturday mornings. For Saturday afternoon and Sunday, these laboratories are only open according to the requirement from the Dean of the FEEE. Each laboratory has its computer system for processing experimental data, conducting statistics, and writing reports related to the experimental results.

Figure 3. Basic Electronic Laboratory at FEEE, DTU

Computing Resources: The Center of IT Lab Management of DTU operates 16 computer laboratories for students from different faculties in the university. There are 710 desktop and workstation computers in these computing laboratories. These computers are primarily Windows-based with a comprehensive set of essential computing software besides LAN connection to a printer and scanner in each laboratory. Out of the 16 computer laboratories, one iMac computing laboratory is mainly used for teaching graphics and sound design courses. All the computers on campus are connected to the DTU fiber optics-based LAN, which in turn also offers access to the Internet. The computing labs are open daily from 7:00 AM to 9:00 PM and offer support to students. The data center is also accessible to Electrical & Electronic Engineering teaching staff from 7:00 AM to 9:00 PM daily for heavy computing processing. Permission is required for students to access the data center for assignments or projects, and it is equipped with 14 Dell blade servers, 7 Cisco routers, 11 Cisco switches, and 2 EMC storage arrays. FEEE provides five workstations in its administrative office for students and teaching faculty members to access the DTU network or the Internet. Faculty members can also access the DTU network with their laptops on campus or remotely through VPN.

Guidance: FEEE faculty members prepare laboratory manuals for each assigned course. These manuals include references, equipment descriptions, safety notifications, and procedures. Safety codes are displayed on posters in labs, and students receive an orientation on safety and general instructions. Faculty and/or lab staff must be present during lab sessions, and students cannot work alone in labs.

Standard 7: Integrated Learning Experiences

As mentioned above, CDIO-based courses are designed to provide practical and strict training in interdisciplinary projects, problem-solving methodologies, team-building skills, and oral, graphical, and written communication skills. For instance, in CDIO Project 2, besides the requirement to design a complete industrial circuit, students must also pay attention to the design optimization factors in terms of cost, performance, energy efficiency, reliability, size, and weight. Not only that, but the design must also ensure the issues of industrial and national environmental standards. Another example is in Graduation Project, students will apply the accumulated knowledge throughout their whole learning process for the design, implementation, or improvement of a particular product or prototype, or process. This should be the novelty of what companies and enterprises in the real world are working on. Its formulation and improvement are always based on serious consideration of global, cultural, environmental, social, economic, ethical, and professional factors. The project is expected to help students consolidate deep knowledge while gaining advanced know-how in their specialty areas through self-training and lifelong study. To achieve that goal, except for supporting tools, students can collaborate with scholars, experts, and industry to learn knowledge from them. Furthermore, students are encouraged to publish or present their work at the conference and journal to obtain more comments for improvement of work.

Standard 8: Active Learning

Active Learning in CDIO typically involves students working in teams on real-world problems and projects and participating in hands-on activities such as design challenges, prototyping, testing, and evaluation. This approach emphasizes collaboration, communication, and critical thinking skills and encourages students to take ownership of their learning. It also involves using various teaching methods and technologies, such as flipped classrooms, case studies, project-based learning, and simulation tools. These methods help to create an engaging and interactive learning environment that encourages students to think creatively, solve problems, and apply their knowledge and skills in real-world situations.The project also encourages students to work independently and collaborate closely with their supervisor(s) and colleagues in the industry to enhance their expertise, communication skills, and vision in Electronic Engineering for later career development.

Standard 9: Enhancement of Faculty Competence and Standard 10: Enhancement of Faculty Teaching Competence

In order to teach this master's program, the lecturer has to have Ph.D. Degree and experience in this EE field. There are several major tracks for professional development for FEEE faculty members, specifically as follows:

FEEE encourages faculty members to attend national and international conferences or workshops, and will financially support those who present at such events. Even if they do not present, faculty members can still take leave with pay if they obtain outside grants for their expenses. The EE master program faculty members have participated in various workshops, including CDIO International Conferences. FEEE supports scientific research expenses, and promotes policies for international publications in well-recognized journals. DTU provides full or partial support for publication fees and awards bonuses or salary increases for research papers published in high-impact journals. FEEE collaborates with local and international companies, enterprises, and societies, and faculty members are required to visit industry companies and enterprises for at least ten days per year, as per DTU policy.

Standard 11: Learning Assessment

The teaching faculty members of FEEE directly assess a student's achievement of certain LOs based on his or her performance in their courses. Students' feedbacks before their graduation are also taken into account for the indirect assessment of those LOs. On a semester basis, the Accreditation Committee of FEEE will collect both direct and indirect assessment data from the teaching faculty members, the students, and the university web portal of myDTU, and the AMS of DTU. The Accreditation Committee of FEEE will discuss the assessment statistics, comments and suggestions for decision making on which improvements and corresponding course of action to be carried out. We have also implemented the DTU Testing Service system, which is synchronized with the LMS and LCMS systems, serving smoothly in questions, exams, and grading afterward. The system automatically links the graded items of each learner in each class to the full scoreboard of all subjects in the school.

The essential courses of the EE master program are mapped to the set of LOs and Pis as demonstrated in Table 1. In order to check the extent to which a specific course has met LOs and PIs, there are two assessment processes:

- Direct Assessment: through schoolwork in a regular course (i.e., Attendance & Discussion in Class (through Pop-Quiz), Quiz, Homework, Practical Application, Midterm Exam, Individual Project, Group Project, Final Exam), Graduation (Capstone) Project report/prototype, Peer review and Graduation (Capstone) Project Defense Session.
- Indirect Assessment: through Exit Survey and Employer Survey.

Standard 12: Program Evaluation

Each LO would be analyzed one after another with the following rounds or phases of work:

- Assessment Results at the end of Spring 2022.
- Improvements & Actions being implemented in Spring 2024.

Each round of general assessment includes the outcome assessment and the following evaluations. The results will include an outcome table followed by the trend line for each outcome throughout the last three general assessments. Each outcome table carries out the benchmarking based on individual PIs and the corresponding host LO alongside the mapped basic courses, assessment methods, data source, timetable, and performance target. The trend lines that follow are on cycles of two years each for both individual PIs and the corresponding host LO.

All the data for the general assessment cycles were already available in the AMS of DTU, which collects and processes students' grades on a semester basis. Students' grades collected ranged from the schoolwork assignment/test question levels to the overall course grade level.

Through the annual Faculty Advisory Board Meetings (once or twice a year with recorded meeting minutes) and other communication channels like email, phone, video conferencing, regular mail, etc., members of the Advisory Board of FEEE help refine the PEOs, and update the curriculum of the EE master program, specifically by:

- Providing advice on ways to revise the PEOs,
- Identifying the right set of capabilities and tools needed for various Electronic Engineering career tracks,
- Offering insights into the current conditions of the local and global markets of the electrical and electronic engineering industry,
- Making recommendations on the course of action to improve the EE master program and its curriculum.

CONCLUSION

In this article, we have presented the EE master program of Duy Tan University in the Industrial 4.0 context. We have described the CDIO framework to assist our students in acquiring the desired knowledge and skills to meet future human resource needs for the Industry 4.0 trend. In addition, we present the level of implementation of this framework of this EE master program according to 12 CDIO standards. Through the implementation of the CDIO project, the outputs are technical reports, design prototypes, and articles published by students that have proven the effectiveness of our EE master program. In future work, we will present this program's continuous improvement to clarify the deployment's effectiveness.

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BIOGRAPHICAL INFORMATION

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PRACTICE-BASED ENGINEERING DESIGN FOR NEXT-GENERATION OF ENGINEERS: A CDIO-BASED APPROACH

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ABSTRACT

In recent years, practice-based learning has been establishing itself as a new norm in higher education: an enabler to foster knowledge, skills and innovative thinking in young learners. Conceive, design, implement and operate (CDIO), a well-established pedagogical methodology, offers many opportunities for education providers seeking to best achieve this practice-based learning within various educational environments. Case studies of engineering programs that made use of the CDIO model provide illustrations of how the ideas were put into effect in actual projects. This paper draws on a CDIO-based design case study where students were requested to solve a real engineering problem; in order to explore the great potential of such a teaching and learning paradigm in practice settings. Some first-year mechanical, biomedical and product design engineering students studying at the Canterbury Christ Church University were set a design brief by a Ford Motor Company tier supplier, to design a high security lock for commercial vehicles which works on both sliding and rear hinged slam doors. The project had twelve engineering groups, each with three or four students sharing responsibility for separate project design and engineering roles: including design sketches; computer-aided modelling; engineering material investigation; finite element analysis; computer-aided manufacturing; prototyping; project reporting and company presentation. In order to analyse the effect of incentives on the underlying motivation of learners, a cash prize was secured via the Engineers in Business Fellowship (EIBF) organisation, to be shared between the winners selected by the industrial partner after a detailed study of benefits, manufacturability and potential innovation. This paper documents the findings of collected qualitative and quantitative data as part of this project-based case study, and furthermore, reflects on the effectiveness of CDIO implementation on the depth of students' knowledge and level of practical engineering learning. The objective here is to evaluate the individual and collaborative learning processes that occur among a group of students as they use CDIO active learning tactics. The analysis reported in this paper can serve as a foundation to illustrate how educators may better prepare their students for joining the workforce of the future, by using an active learning approach that provides more weight to practical than theoretical knowledge.

KEYWORDS

Practice-based learning, Inclusive learning, CDIO implementation, AHEP 4.0, Standards 3.0

INTRODUCTION

Throughout the years, a combination of theoretical and active learning experiences through practice (Gómez Puente, 2011) have been used to educate and develop engineers into professionals who work to meet industrial demands. Learning opportunities from collaborations between industry and higher education lead to mutually beneficial solutions generated for all, including the stakeholders, and produce industry ready engineering graduates, (Chew et al, 2021). With industry supplying real design briefs for students to work upon, this provides opportunities for students to learn and develop their engineering design and employability skills, (Morgan & O'Gorman, 2010). Adopting a constructivist approach shifts the learning from academics being transmitters of knowledge, to facilitating students to learn through experience and activity-based study (Briede, 2013).

Conceive, design, implement, operate (CDIO) is a pedagogical method that offers rational, universal, complete, and generalisable goals for engineering education (CDIO, 2022). The CDIO standard of design-implement experiences enables students to conceptualise a design and implement it, applying their engineering learning in practice. This is done primarily through emphasising engineering fundamentals in an engineering programme. While 3D printing technology enables students to rapid prototype their designs, aiding in the breadth and depth of their learning of design, (Ford, & Minshall, 2019). The 3D printers add a CDIO pedagogical approach and enable students to explore their designs, failures, geometry, and tolerances in practice, (Haavi et al., 2018).

CDIO framework is developed to improve the learning and teaching standards for students in any discipline and in particular, the science and engineering fields. The positive impact on the students learning has also been observed in online courses (Shah & Foster, 2022). There are numerous advantages associated with the implementation of CDIO principles in digital learning and remote learning scenarios. These advantages include but are not limited to an improved flexibility of delivery, accessibility, and enhanced collaboration amongst students which result in significant improvement of the technical and non-technical skills in learners. This finding is observed in the latest publication of Martins et al. (2023), where students demonstrated an improved communication, critical problem solving and strategic thinking skills to tackle scientific challenges in a CDIO based course. The results also shed light on the importance of incorporating real-world scenarios and projects to provide students with an opportunity to learn productive team work cross-disciplinary. Lopes et al. (2022)'s research further emphasise on this in work-based learning courses where the incorporation of real-world projects resulted in better understanding the application of theory in practice. It was revealed that students were better able to bridge the gap between theory and practice and appreciate the need for continuous learning throughout their professional lives.

Delving into other studies on CDIO practices in engineering, Zhang et al. (2022) has introduced a novel method to develop engineering curriculums with sustainability at their core. The aim of this research is to equip students with skills required to integrate sustainability in every engineering project. The CDIO based approach to creating opportunities for students to infuse sustainability principles in their engineering coursework is an essential step towards educating environmentally aware engineers for the future. Upon graduation, students will be well educated to work on multi-disciplinary and innovative projects with environmental sustainability principles in mind. The benefits of problem-based learning of CDIO in engineering fields were further explored by Hu et al. (2022), where the findings showed promising improvement in students' engagement in course activities. Students were found to have more enthusiasm and confidence in tackling collaborative projects based on real-world scenarios.

There are many case studies offering sure proof of positive advantages associated with CDIO based learning. However, all studies concur that no benefits will be achieved without a strategic approach towards planning for the effective adoption and implementation of CDIO principles in science and engineering curriculums. Case studies demonstrate the significance of resource allocation, industry engagement, and technological facilities to fully embrace the fruits of CDIO in education.

At Canterbury Christ Church University (CCCU), a CDIO project aimed at improving the design and manufacturing of locks was defined in collaboration with Advanced Metal Components (AMC) Ltd, a company that specializes in CNC machining and manufacturing of locks for their client, Ford Motor Company. A prize of £3000 was also secured through the Engineers in Business Fellowship (EIBF) for the winning team, as chosen by AMC after a thorough evaluation of benefits, manufacturability, and potential innovation. The students were tasked with designing a high-security lock for commercial vehicles that can be used on both sliding and rear hinged slam doors, which are often added to vans as a theft deterrent. The lock was required to have a standard euro lock insert, a robust and resistant main body, and easy-to-assemble mechanical components. Additionally, the design needed to be appealing to Ford Motor Company, who were considering a custom design from AMC. The project was divided into twelve engineering groups, each consisting of three or four students, responsible for various aspects of the project: including design sketches; 3D CAD product development; material investigation; finite element analysis; computer-aided manufacturing; prototyping; project reporting; and company presentation.

Five group reports were reviewed in line with the desired outcomes of implementing CDIO. Learning points and areas for improvement were discussed. Past exam data was also reviewed for various protected groups to further highlight the benefit of using this training model to develop future engineers.

REPORT REVIEW

Five sample reports were analysed in line with the assignment brief's requirements and what one would expect of a student who has studied under CDIO's guidelines and expectations. A group of first-year year undergraduate mechanical, biomedical, and product design engineering students were tasked with the design and analysis of a slam lock. The lock was to be designed to automatically lock when it is slammed shut but have an internal release in case a user is stuck in the cargo area. It should be made of materials strong enough to enable it to resist any attack with power tools nor should it be possible to lever it open, and it should be versatile enough to be used on a rear barn-type door or a side sliding door. Other design parameters and guidelines were provided in the assessment brief. The main activities that were expected from all students were:

- **Design sketches and drawings:** design concepts were expected, as students should be able to conceptualise the design that they are to make. This allowed them to create either hand-drawn sketches of the design concepts or a combination of both hand-drawn sketches and technical drawings. If technical drawings were submitted, they had to be aligned with BS8888 engineering drawing standards.
- **CAD models:** students were required to submit 3D computer-aided design models of the finished product. These models were to be made with manufacturability and mass production in mind. They were also asked to reflect the designer's intent and highlight the product's features.

- **FEA analyses:** finite element analysis (FEA) should be used to demonstrate how the product and its individual components behave when various loads are applied on them. It would be useful to consider expected loads, i.e., those that are exerted during handling, as well as those that are exerted during forced entry. The latter demonstrates the product's ability to perform safely during a break-in. Aspects of FEA such as mesh convergence and mesh refinement had also to be demonstrated, to show an understanding of FEA and how the accuracy of results can be improved (Autodesk, 2015).
- **CAM simulations:** these had to be carried out to demonstrate the manufacturability of the product's components using computer-aided manufacturing simulation. This had to be done for at least one of the components. Once this had been demonstrated virtually, the manufacturing code/gcode for the component was to be produced and transferred to a CNC machine or a 3D printer for the practical production of the component.
- **Manufacturing:** one component was to be manufactured as part of the prototyping phase. Either traditional manufacturing or rapid prototyping may be used at this stage. Professional practice skills such as health and safety, appropriate use of machinery, and safe usage of the final product was assessed.
- **Results analyses and presentations:** all findings were to be presented in a 4500-word report and an 800-word poster. The overall evaluation had to address how the mass and cost of the components can be reduced without negatively affecting the part's structural integrity. Report writing and presentation skills was addressed in line with professional presentation standards.

CASE STUDY 1

This report included hand-drawn sketches, annotations and dimensions, two-dimensional and three-dimensional diagrams, detailed CAD models of each component and the final assembly was produced and rendered to a high standard.

Detailed FEA analysis was done to a significant level of detail. The component's bolt was tested to determine whether high-strength alloy steel or mild steel should be used. The decision was made based on the loading test, which yielded different results for the softness of material. The report demonstrated a good understanding of FEA and how it can be used to design and test a component pre-manufacture (Bi, 2018).

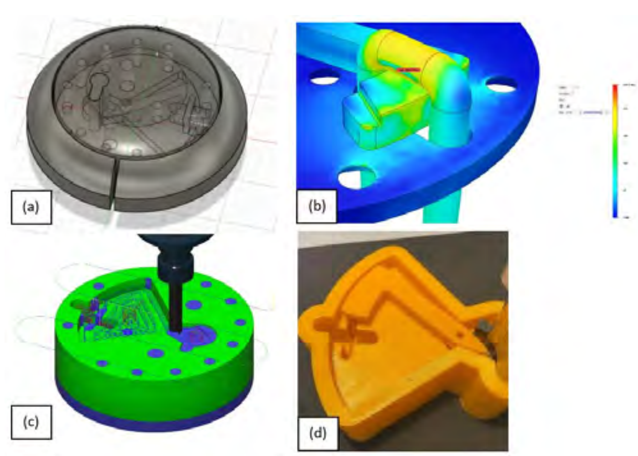

Figure 1: Case Study 1 project outcome: (a) CAD Model, (b) FEA Analysis, (c) CAM Simulation, and (d) Prototype

Rapid prototyping was used to manufacture the design and corrective measures were detailed; which demonstrated a good understanding of product functionality and the ability to correct issues that result from factors that are out of the students' control (which was the quality of the printed product, in this case). The report satisfied the research requirements of the assignment in quality and depth.

CASE STUDY 2

This report started off with market research, an important aspect of engineering design and a good student initiative. Existing designs were critically investigated to determine the optimum design concept. The outer shell and internal locking mechanism concepts were finalised with annotations, based on the preliminary hand-drawn sketches. Both linear and non-linear FEA analyses were carried out on the component, to provide information on the product's performance during loading in a more natural scenario (Femto, 2021). Computer-aided manufacturing simulations were carried out on most of the product's components, with the spring and bolts being the only parts that would be outsourced. This demonstrates an appreciation of production cost-cutting measures which are useful in reducing production times, costs, and floor space in factories. The parts were then 3D printed, but this study did not have much success with rectifying the previously mentioned printing issues to produce a working prototype. An FMEA (failure mode and effects analysis) was carried out on the process used to make the finished product, which will come useful for the students' future design and production endeavours (Weibull, 2022).

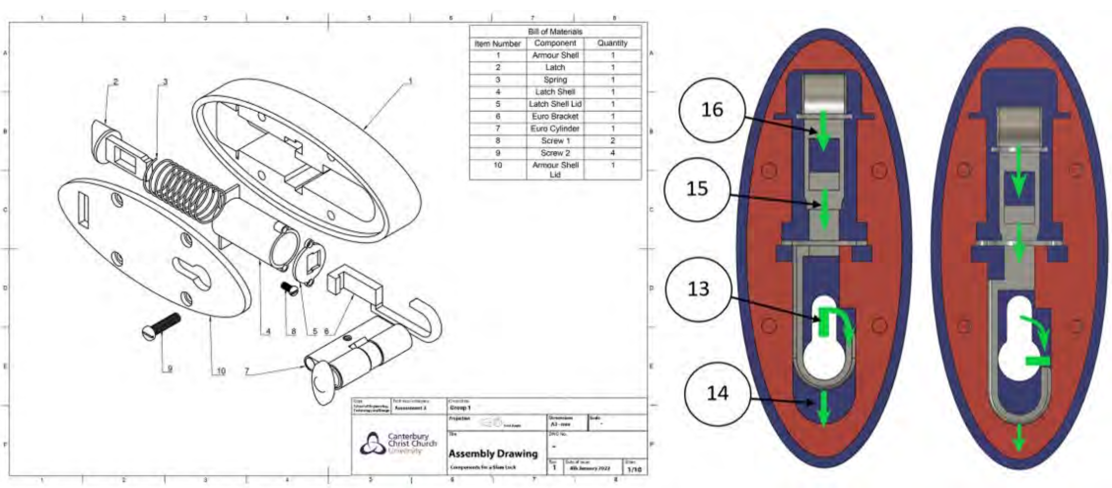

Figure 2: Case Study 2 project technical drawing and latching mechanism

Although this group failed to present a high-quality product due to mismanagement of time and the 3D printing challenges, the report demonstrated a fair understanding of product design which compliments the use of CDIO methods, principles and reflections on the opportunities for improvement in the engineering and themselves.

CASE STUDY 3

This report started off with the problem statement and requirements. Research on cost, materials, and design potential were used to develop sketches of various concepts and which demonstrated a good appreciation of the importance of science backed design principles (CES, 2019). Although the CAD work was detailed, the FEA lacked sufficient details. The finished component was successfully 3D printed and assembled. Areas of improvement for design production and testing were noted, along with health and safety considerations, which demonstrated an awareness of quality control and process improvement.

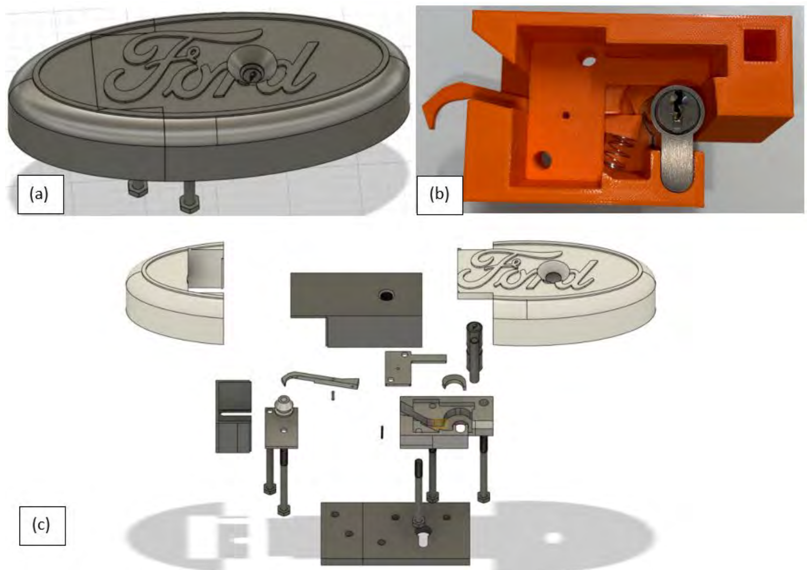

Figure 3: Case Study 3 project outcome: (a) CAD Model, (b) Prototype, (c) Internal Mechanism

CASE STUDY 4

This report was less detailed than the previous three. However, most of the key elements were covered. A risk assessment was done for the production work, and the main hazard stated had a proposed mitigating measure that was carried out on the same day. The FEA, CAM and technical drawings lacked sufficient details and the presentation of the work lacked structure. Despite the downfalls, knowledge of the key technical aspects of the project was well demonstrated.

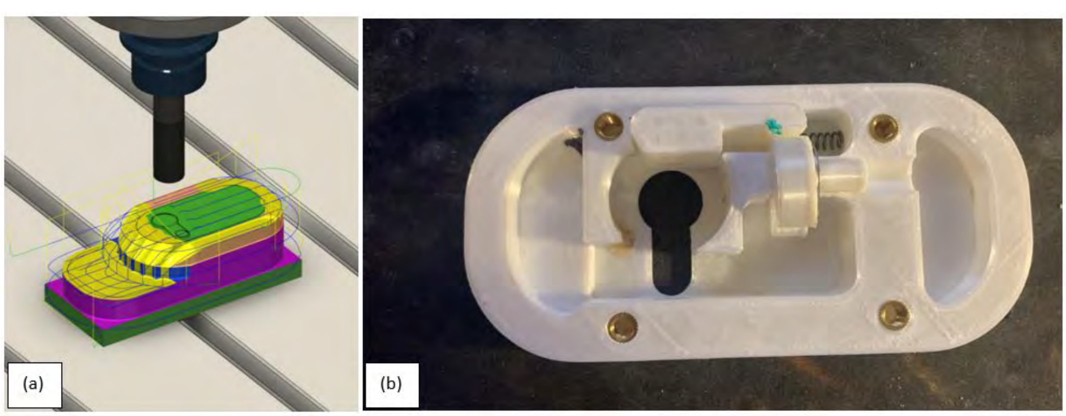

Figure 4: Case Study 4 project outcome: (a) CAM Simulation and (b) Prototype

CASE STUDY 5

The fifth report covered the key aspects of the project, but required some improvements in the order of the information presented and the organisation of the images provided. A mind map was drawn to illustrate how the final design was arrived at, which was coupled with some hand-drawn sketches. A quality function deployment (QFD) diagram was used to incorporate what the students determined to be the voice of the customer into the design of the final product (ASQ, 2022). The CAD models, FEA, and CAM were presented to a professional level, and an evaluation of the work done was also carried out. The 3D printed models were not adequate and resulted in an incomplete product when compared to the products that the other groups manufactured, but still sufficiently fulfilled the assessment brief.

OVERALL FINDINGS

The application of CDIO principles throughout the engineering course enabled students to enhance their critical thinking skills in the design and build of engineering products and systems. Although the case studies discuss five groups, findings were applicable to all twelve groups involved in the course. The findings demonstrated varying capabilities and performance degrees across the groups, but the positive impact of CDIO principles was evident in all groups.

The basic principles of CDIO were evident in the five groups under study, with knowledge of technical and professional engineering concepts and practices being demonstrated. Each group had its strengths and weaknesses, and the strengths were rooted in professional engineering practices. Elements such as market analyses, detailed FEA and CAM processes, risk assessments, and the use of QFDs were all touched on. With more training, students will master these and other relevant skills well before they are ready to pursue their future career as engineers. Also, the incorporation of cross-disciplinary collaboration throughout the course can prove both challenging and beneficial for the students. Despite potential miscommunications, diversity of thought and equal opportunities bring valuable solutions to engineering problems that can bring new horizons to the engineering sector.

STUDENT SURVEY

To give a stronger case for CDIO, a survey was designed based on the AHEP 4.0 learning outcomes for first-year students, to determine the skills acquired in this academic year. The main skills acquired were: designing for integration to standard components, fixes and fittings; engineering modelling; engineering measurement; engineering problem identification; engineering finite element analysis; and engineering computer-aided manufacturing. Skills like inclusive design or finish processes had the lowest scores, which in future module iterations will be addressed by promoting students to improve their design through systematic review and formative feedback from the academics.

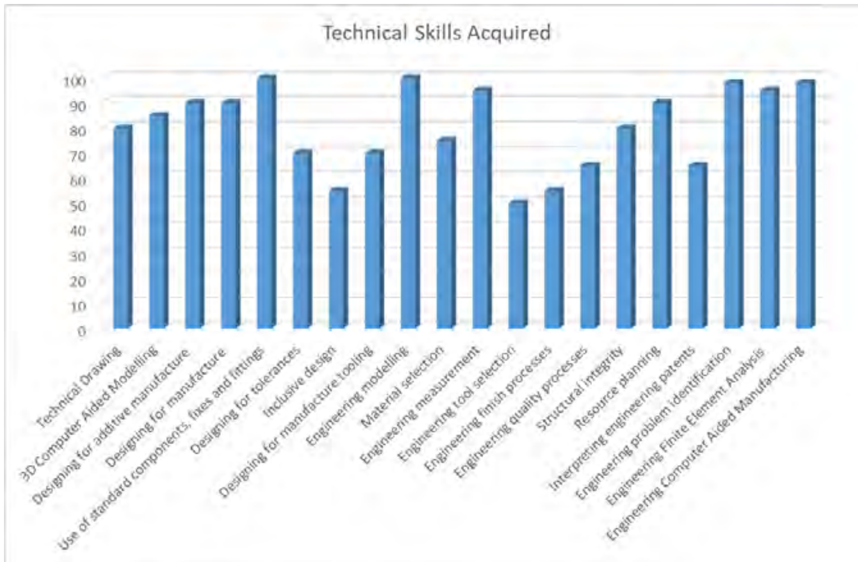

Figure 5: Survey results for technical skills acquired

The graph below shows the employability skills acquired by the end of the module.

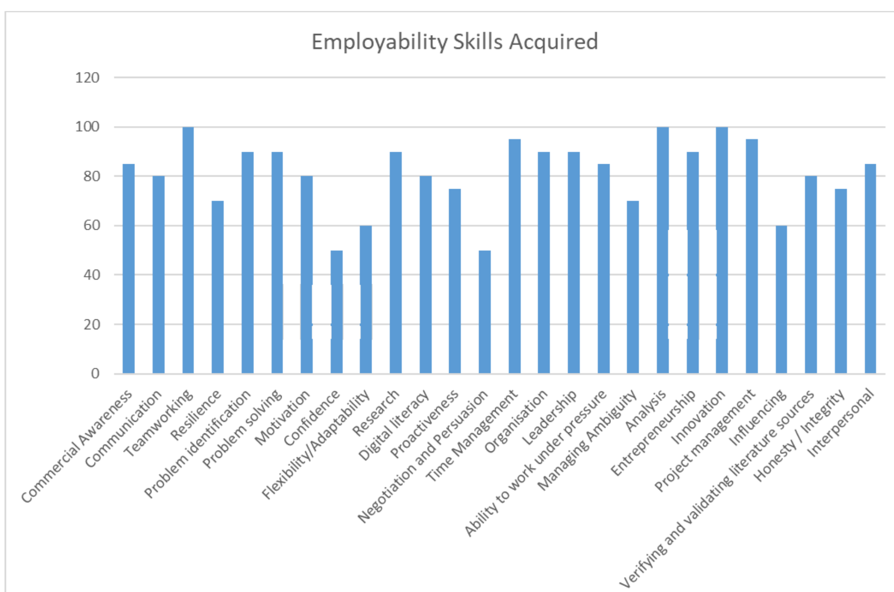

Figure 6: Survey results for employability skills acquired

The main employability skills acquired were: teamworking; problem identification; problem solving; research; time management; organisation; leadership; analysis; entrepreneurship; innovation; and project management. Skills such as negotiation, persuasion, and confidence scored lowly, which is common in students adjusting to the academic environment.

The graph that follows shows the proportion of students who have applied personal developmental practices in line with Engineering Council Accreditation Higher Education Programmes (AHEP) 4.0 guidelines (Engineering Council, 2019).

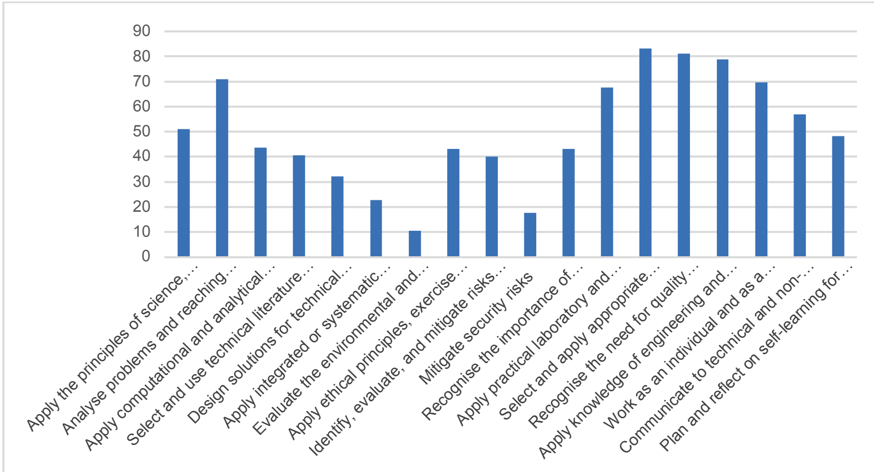

Figure 7: Survey results for other skills acquired

Working as an individual and a member of a team, applying knowledge of engineering and project management to the project, and analysing problems and reaching substantial conclusions were the three main skills that were applied by students. Other skills like mitigating security risks, evaluating the environmental and social impact of problem solutions, and recognising the importance of equality, diversity, and inclusion in the workplace can also be developed. Perhaps students are keener on learning and implementing technical skills over social and employability skills, because this is what engineers are primarily known for, and this needs to be addressed in light of the ever-changing demands of globalisation (NGEC, 2016).

The graph below shows the feedback from students about their overall experience in their first engineering academic year, which are overly positive, with most students finding it good, useful, satisfying, helpful, and excellent. Few found it challenging, and no one found it difficult.

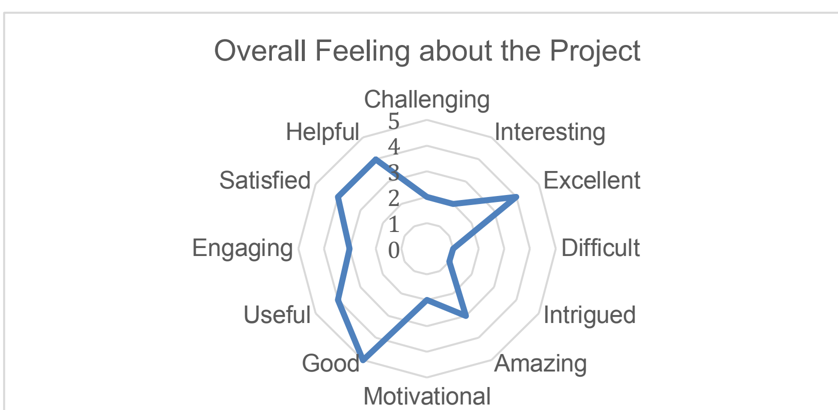

Figure 8: A graph showing the survey results for the overall feeling about the project

The evidence demonstrates discrepancies in the students' abilities to evaluate their performance in leadership, discussion skills and self-confidence attributes. These findings can assist educators in closing the gap between perception and experience to support learners in their weak areas and provide growth opportunities along their academic journeys. As per the CDIO's third standard self-assessment rubric, the iterative improvement and revision of the course, based on students feedback corresponds to the level 5 of the compliance rubric.

STUDENT ATTAINMENT RESULTS

This research offers a unique outlook on the contributing factors to students' performance and engagement across all three years. The first year was void of industry engagement and no incentive was in place. In the second and third years, industry led CDIO projects were introduced to offer students the opportunity of working on real-world projects. The third year also benefited from cash prize incentives to the best project output.The graph below shows how different student from different demographics performed in the assignment in the 2020-2021 academic year; it illustrates the first-time pass rates.

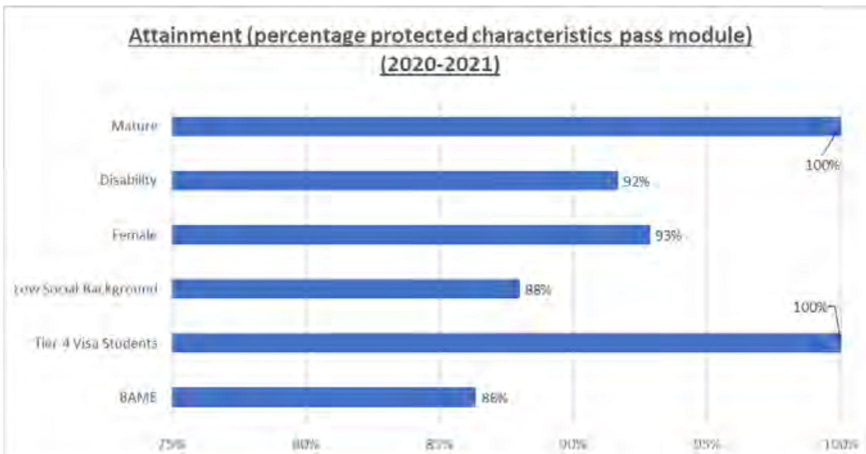

Figure 9: Attainment first-time pass rates for different demographics (2020-2021)

The results show that the attainment rates for all the groups were high, with the black and Asian minority ethnic (BAME) group having the lowest group first-time pass rate at 86% (still above UK norm), and both mature and tier 4 visa students having 100% first-time pass attainment rates. Future research should investigate the underpinning problems and seek remedial action. The graph in the next figures (10 and 11) shows results in the following year, with a notable difference being the use of an incentive for good performers.

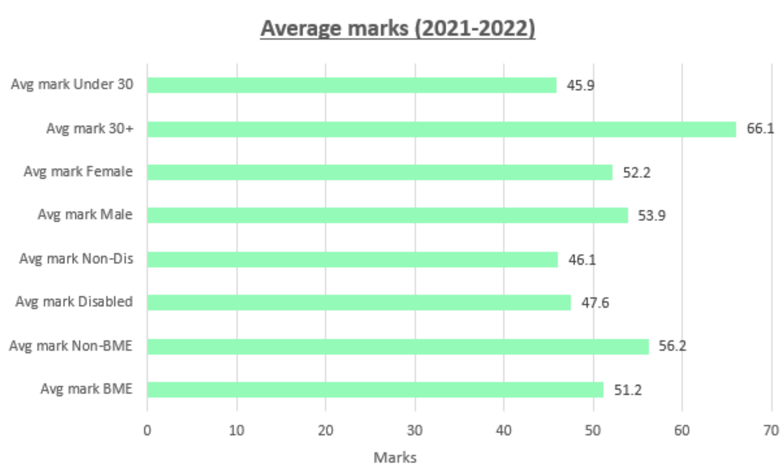

Figure 10: Average marks for different demographics (2021-2022)

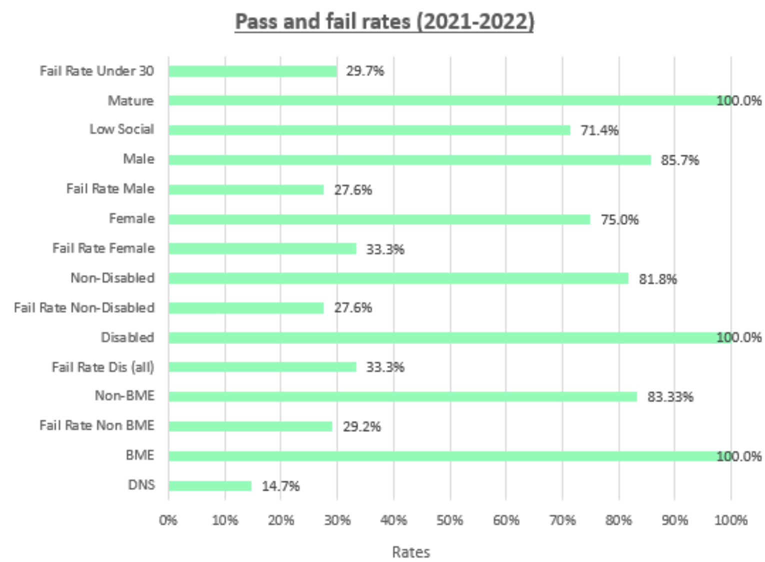

Figure 11: Pass and fail rates for different demographics for 2021-2022

The data shows that, using CDIO, mature students performed significantly better than their younger counterparts, but performances between other groups are closer, which is a positive outcome in closing the BAME attainment gap. This attainment gap between BAME and non-BAME students is 17% or more in the UK (Nortcliffe et al., 2022). Male students performed slightly better than female students, disabled students performed marginally better than non-disabled students. The use of an incentive also shows promising results with disabled people and BAME students recording 100% pass rates. The results for the following year follow a similar trend as shown below:

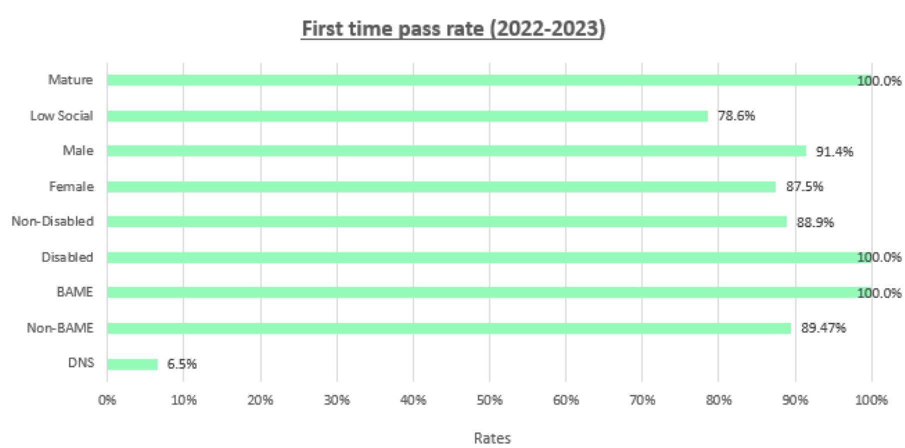

Figure 12: First-time pass rates for different demographics for the 2022-2023 academic year

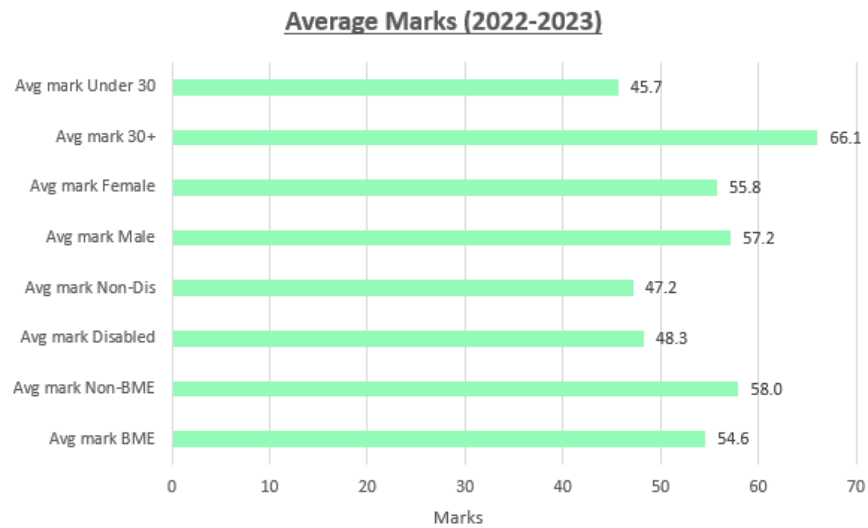

Figure 13: Average marks for different demographics (2022-2023)

There are no notable differences between marks and the prevailing protected characteristics when compared to the previous academic year. The only difference is that the marks are higher in all cases except in the case of the under 30s, where the average mark is lower. Further research is required to determine the cause and effect and the appropriate actions.

CONCLUSION

In conclusion, the results of using the CDIO are clear, as shown in the five reports, and the level of engagement by students on this engineering course and those that were analysed in the surveys is high. The main points of this teaching and learning method, conceiving, designing, implementing, and operating, were all successfully indicated in the five reports that were analysed, albeit at distinct levels.

The comparative analysis of the learning outcomes with the AHEP 4.0 requirements illustrates that all five groups demonstrated good knowledge and application of mathematical, engineering, and natural science principles to the design and production problem. Problem solving and analytical skills were also evident, although, further use of technical literature could support scientific justification. The fourth report in particular lacked significantly in this area, despite the good technical work done. The products were meticulously designed and illustrated, but some of the groups did not properly show how they arrived at their chosen concepts. The groups did well generally when it came to addressing the social aspects of the project, such as designing the product against forced entry and carrying out risk assessments to mitigate or eliminate hazards at the workplace. Further practice will enable these students to better address issues such as ethics, sustainability, and diversity (Engineering-Council, p. 2019). The use of contemporary engineering technologies was demonstrated well by all the groups, and with more practice, their usage will improve in quality and professionalism. Communication could be improved, especially when report formatting and presentation are improved. Overall, all groups achieved the learning outcomes outlined in AHEP 4.0’s guidelines, which can be attributed to the use of CDIO.

Amelioration of student performance and engagement is only possible through a strategic approach encompassing the following considerations:

a. Periodic assessment to evaluate students' weaknesses that can be addressed in tailored tutorials or one-to-one support sessions designed to meet every students' particular need to perform their best.
b. Integration of problem-based learning in the delivery program to ensure students gain in-depth understanding of engineering fundamentals and their application in practice.
c. Incorporate training for interpersonal skills including time-management, and productive studying methods, where a growth mindset is encouraged to enable students overcome challenges throughout their academic and professional lives.
d. Provide access to various teaching materials, including digital tools to empower students and create a safe space for anyone struggling with physical or mental challenges that may impede their learning abilities.
e. Promote collaboration and teamwork amongst students to develop a productive environment both inside and outside the classroom, where peer support gives power to those with lower performances and boosts enthusiasm amongst all students.
f. Conducting regular feedback sessions coupled with monitoring students' progress can support improving delivery strategies and identifies any need for further resources required by the institution to support all learners.

The abovementioned considerations can ensure an all-encompassing approach towards improving the learning of underperforming students. The research also highlights the positive impact of incentives on the students' attainment results; however, more test samples are required for a more reliable inference, which can be addressed by future research.

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Appendix A

Area of learning	Incorporated Engineer Foundation degrees, Higher National Diplomas and equivalent qualifications and apprenticeships approved or accredited as fully meeting the academic requirement for EngTech registration and partially meeting the academic requirement for IEng registration	Bachelors Top-up degrees and equivalent qualifications and apprenticeships approved or accredited as meeting the requirement for further learning for IEng registration	Bachelors degrees and Bachelors (Honours) and equivalent qualifications and apprenticeships approved or accredited as fully meeting the academic requirement for IEng registration
On successful completion of an approved or accredited programme, an individual will be able to:			
Science and mathematics The study of engineering requires a substantial grounding in engineering principles, science and mathematics commensurate with the level of study.			
Science, mathematics and engineering principles	F1. Apply knowledge of mathematics, statistics, natural science and engineering principles to broadly-defined problems.	B1. Apply knowledge of mathematics, statistics, natural science and engineering principles to broadly-defined problems. Some of the knowledge will be informed by current developments in the subject of study.	B1. Apply knowledge of mathematics, statistics, natural science and engineering principles to broadly-defined problems. Some of the knowledge will be informed by current developments in the subject of study.

Figure A1: A table showing the science, engineering, and mathematics learning outcomes for students studying at bachelors' level and below (Engineering-Council, 2020)

Area of Learning	Incorporated Engineer (continued) Foundation degrees, Higher National Diplomas and equivalents (continued)	Bachelors Top-up degrees and equivalents (continued)	Bachelors degrees and Bachelors (Honours) and equivalents (continued)
On successful completion of an approved or accredited programme, an individual will be able to:			
Engineering analysis Engineering analysis involves the application of engineering concepts and tools to analyse, model and solve problems. At higher levels of study engineers will work with information that may be uncertain or incomplete.			
Problem analysis	F2. Analyse broadly-defined problems reaching substantiated conclusions.	B2. Analyse broadly-defined problems reaching substantiated conclusions using first principles of mathematics, statistics, natural science and engineering principles.	B2. Analyse broadly-defined problems reaching substantiated conclusions using first principles of mathematics, statistics, natural science and engineering principles.
Analytical tools and techniques	F3. Use appropriate computational and analytical techniques to model broadly-defined problems.	B3. Select and apply appropriate computational and analytical techniques to model broadly-defined problems, recognising the limitations of the techniques employed.	B3. Select and apply appropriate computational and analytical techniques to model broadly-defined problems, recognising the limitations of the techniques employed.
Technical literature	F4. Select and use technical literature and other sources of information to address broadly-defined problems.	B4. Select and evaluate technical literature and other sources of information to address broadly-defined problems.	B4. Select and evaluate technical literature and other sources of information to address broadly-defined problems.

Figure A2: A summary of the problem solving and analytical learning outcomes for bachelor-level students (Engineering-Council, 2020)

Area of learning	Incorporated Engineer (continued)		
	Foundation degrees, Higher National Diplomas and equivalents (continued)	Bachelors Top-up degrees and equivalents (continued)	Bachelors degrees and Bachelors (Honours) and equivalents (continued)
On successful completion of an approved or accredited programme, an individual will be able to:			
Design and innovation Design is the creation and development of an economically viable product, process or system to meet a defined need. It involves significant technical and intellectual challenges commensurate with the level of study.			
Design	F5. Design solutions for broadly-defined problems that meet a combination of user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal and environmental matters, codes of practice and industry standards.	B5. Design solutions for broadly-defined problems that meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.	B5. Design solutions for broadly-defined problems that meet a combination of societal, user, business and customer needs as appropriate. This will involve consideration of applicable health and safety, diversity, inclusion, cultural, societal, environmental and commercial matters, codes of practice and industry standards.
Integrated/systems approach	F6. Apply a systematic approach to the solution of broadly-defined problems.	B6. Apply an integrated or systems approach to the solution of broadly-defined problems.	B6. Apply an integrated or systems approach to the solution of broadly-defined problems.

Figure A3: A summary of the design and systems' approach learning outcomes (Engineering-Council, 2020)

Area of learning	Incorporated Engineer (continued)		
	Foundation degrees, Higher National Diplomas and equivalents (continued)	Bachelors Top-up degrees and equivalents (continued)	Bachelors degrees and Bachelors (Honours) and equivalents (continued)
On successful completion of an approved or accredited programme, an individual will be able to:			
The engineer and society Engineering activity can have a significant societal impact and engineers must operate in a responsible and ethical manner, recognise the importance of diversity, and help ensure that the benefits of innovation and progress are shared equitably and do not compromise the natural environment or deplete natural resources to the detriment of future generations.			
Sustainability	F7. Evaluate the environmental and societal impact of solutions to broadly-defined problems.	Learning outcome achieved at previous level of study.	B7. Evaluate the environmental and societal impact of solutions to broadly-defined problems.
Ethics	F8. Identify ethical concerns and make reasoned ethical choices informed by professional codes of conduct.	B8. Identify and analyse ethical concerns and make reasoned ethical choices informed by professional codes of conduct.	B8. Identify and analyse ethical concerns and make reasoned ethical choices informed by professional codes of conduct.
Risk	F9. Identify, evaluate and mitigate risks (the effects of uncertainty) associated with a particular project or activity.	B9. Use a risk management process to identify, evaluate and mitigate risks (the effects of uncertainty) associated with a particular project or activity.	B9. Use a risk management process to identify, evaluate and mitigate risks (the effects of uncertainty) associated with a particular project or activity.
Security	F10. Adopt a holistic and proportionate approach to the mitigation of security risks.	Learning outcome achieved at previous level of study.	B10. Adopt a holistic and proportionate approach to the mitigation of security risks.
Equality, diversity and inclusion	F11. Recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion.	Learning outcome achieved at previous level of study.	B11. Recognise the responsibilities, benefits and importance of supporting equality, diversity and inclusion.

Figure A4: A summary of the social learning outcomes for students studying at bachelors' level (Engineering-Council, 2020)

Area of learning	Incorporated Engineer (continued)		
	Foundation degrees, Higher National Diplomas and equivalents (continued)	Bachelors Top-up degrees and equivalents (continued)	Bachelors degrees and Bachelors (Honours) and equivalents (continued)
On successful completion of an approved or accredited programme, an individual will be able to:			
Engineering practice The practical application of engineering concepts and tools, engineering and project management, teamwork and communication skills. Engineers also require a sound grasp of the commercial context of their work, specifically the ways an organisation creates, delivers and captures value in economic, social, cultural or other contexts.			
Practical and workshop skills	F12. Use practical laboratory and workshop skills to investigate broadly-defined problems.	Learning outcome achieved at previous level of study.	B12. Use practical laboratory and workshop skills to investigate broadly-defined problems.
Materials, equipment, technologies and processes	F13. Select and apply appropriate materials, equipment, engineering technologies and processes.	Learning outcome achieved at previous level of study.	B13. Select and apply appropriate materials, equipment, engineering technologies and processes.
Quality management	F14. Recognise the need for quality management systems and continuous improvement in the context of broadly-defined problems.	Learning outcome achieved at previous level of study.	B14. Recognise the need for quality management systems and continuous improvement in the context of broadly-defined problems.
Engineering and project management	F15. Apply knowledge of engineering management principles, commercial context and project management.	B15. Apply knowledge of engineering management principles, commercial context, project management and relevant legal matters.	B15. Apply knowledge of engineering management principles, commercial context, project management and relevant legal matters.
Teamwork	F16. Function effectively as an individual, and as a member or leader of a team.	Learning outcome achieved at previous level of study.	B16. Function effectively as an individual, and as a member or leader of a team.
Communication	F17. Communicate effectively with technical and non-technical audiences.	Learning outcome achieved at previous level of study.	B17. Communicate effectively with technical and non-technical audiences.
Lifelong learning	F18. Plan and record self-learning and development as the foundation for lifelong learning/CPD.	Learning outcome achieved at previous level of study.	B18. Plan and record self-learning and development as the foundation for lifelong learning/CPD.

Figure A5: A summary of the engineering practice learning outcomes (Engineering-Council, 2020)

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FRAMEWORK FOR THE EVALUATION OF CYBERSECURITY CURRICULUM EDUCATIONAL CONTENT

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ABSTRACT

In this research, we define a framework for identifying the educational content of an existing university-level cybersecurity curriculum and aligning it with educational requirements distilled from the combination of the European cybersecurity taxonomy and European Cybersecurity Skills Framework, which identifies distinct role profiles with different educational requirements for cybersecurity professionals. We take the cybersecurity roles and skills frameworks and connect them with the knowledge areas defined in the European cybersecurity taxonomy. As a result, we can clearly identify the necessary knowledge areas for each individual role, and also align them with individual course contents in the cybersecurity curriculum. This makes it possible to identify gaps in existing curricula and ensure that educational content meets the requirements of expected knowledge areas. The developed framework is validated by using it to evaluate an existing university level cybersecurity curriculum at University of Turku, where engineering education curriculum follows the CDIO model. The results are used to identify the gaps in current educational content and to verify that the educational content sufficiently covers the desired role profiles. It is also used to provide input for board level decision-making on cybersecurity education. In addition, the assessment phase also provides important feedback for further development of the framework towards a tool that can be used to shape wider educational policy on cybersecurity education beyond individual universities.

KEYWORDS

Cybersecurity, Course development, ECSF Framework, ECT Taxonomy, Standards: 3, 7, 8, 12

INTRODUCTION

Cybersecurity plays a critical role in the fabric of modern society and industry. Recent research has identified a shortage of cybersecurity professionals both in the private and public sectors. In an attempt to accurately assess the current situation in Finland, a recent report by the University of Jyväskylä found that there is a need in Finland for between 6000 and 13000 new cybersecurity professionals in the next few years (Lehto, 2022). This creates and places great expectations on higher education institutions to provide high-quality education in cybersecurity that will lead to skilled cybersecurity professionals in the labour market. Cybersecurity, therefore, needs to be prioritized in education.

At the University of Turku (UTU), a previously identified shortage of cybersecurity professionals through experience and partners served as an important motivator for developing the existing curriculum and the content of individual courses. The University of Turku's curriculum is largely built on the best understanding of what the course content should include, based on the best judgment of cybersecurity teachers and the industry network. The teaching of the Department of Computing includes CDIO-based approaches and the University of Turku's Information Technology education has been accredited on the basis of EUR-ACE accreditation (UTU, 2022), but accreditation does not include a systematic content review to allow further development of the courses. The curriculum of the University of Turku also meets the requirements of the EIT Digital Master School for Cybersecurity (EIT, 2022) and received the EIT Label in 2023 (EIT, 2023). Yet, there is a clear desire to improve existing courses and curricula in a more systematic way and to identify areas for prioritization or expansion.

Currently, there are no appropriate and effective tools to assess and design a university-level cybersecurity curriculum that also considers the wider societal and sectoral interests related to the role and educational profile of cybersecurity graduates. Such tools are needed to successfully design and implement a curriculum that both meets the societal needs of security professionals and ensures that cybersecurity-specific educational requirements are met. The University of Jyväskylä's report (Lehto, 2022) uses the NIST National Cybersecurity Workforce Framework (NIST, 2020b);(NIST, 2020a) to make a more granular assessment of the professional profile of the new professionals. While the report clearly identifies the need for new professionals and provides an assessment of the estimated numbers for each NIST NCWF category, it lacks the link between what is needed in the workforce and what universities should be teaching to meet this demand. More precise and robust definitions and categories are needed to help design and implement new cybersecurity curricula that are likely to deliver the desired outcomes. This paper provides the missing link between educational content, professional skills, and industry demand. Our approach is not limited to cybersecurity education, as the framework can be applied to other engineering fields with similar existing bodies of knowledge and well-defined professional profiles for industry practitioners. In this case, the general process is the same: extract essential knowledge and competence from the professional profile and map it to course content.

PREVIOUS WORK

There is currently a high expectation and need to increase the number and skills of cybersecurity professionals. Due to the pressure on universities from different stakeholders, universities must find ways to develop and integrate course contents and curricula to fulfill the requirements on professionalism without increasing credit requirements (Harris & Patten, 2015); (Kans, 2016). Understanding different stakeholders and their demands on education and curriculum content is an important input for curriculum decisions. Previous research has highlighted the importance of teachers and other academic staff having a direct influence on education by defining content and format (Roberts, 2015). In addition, several different approaches have been used to develop course content and curricula. For example, development work has been started to be built through Bloom's taxonomy (Harris & Patten, 2015), accreditation requirements (Knapp, Maurer, & Plachkinova, 2017), program evaluation based on standards (Brink et al., 2020), and in-house development work, surveys for students, teachers, alumni, and companies (Kans, 2016). Knapp et al. (2017) also suggest that the cybersecurity curriculum should include an annual review of key professional certifications and the department should enable professional certification of teaching personnel (Knapp et al., 2017).

Bloom's taxonomy, accreditations, and internal development activities are good starting points for the development of cybersecurity courses. But the challenge is that these approaches do not lead to a systematic review or development of course content. Other approaches are needed to achieve this. These approaches do not allow for a bridging of the transition from basic studies to working life, for example in the form of future job roles.

The European Cybersecurity Skills Framework (ECSF) (ENISA, 2022) is a framework developed by the European Union Agency for Cybersecurity (ENISA). Its purpose is to facilitate the identification of key tasks, skills, knowledge, and competencies for identified cybersecurity professional roles. The stated goals of the ECSF are, paraphrased, to ensure common terminology and shared understanding on cybersecurity between demand and supply sides, support the identification of critical skills from a workforce perspective, facilitate understanding of cybersecurity and essential skills for non-technical experts, harmonization in cybersecurity education, training and workforce development, and a standard structure on capacity building inside the European cybersecurity workforce. The ECSF provides the first European framework and definitions for cybersecurity professionals. There are 12 identified role profiles in the ECSF, and for each profile, the framework identifies required key skills, knowledge, tasks, and competencies. The ECSF Framework is strongly linked to *The European e-Competence Framework (e-CF)*, standard EN 16234-1 (European Committee for Standardization, 2019). The e-CF is is a common European framework for ICT Professional competences, knowledge and skills, which relates to competences needed and applied at the workplace (ENISA, 2022).

SPARTA project used a cybersecurity skills framework to create a free tool called Cybersecurity Curricula Designer (SPARTA, 2022a). The work roles and competencies used in the Curricula Designer reflect the requirements of the Workforce Framework for Cybersecurity (NICE Framework) (SPARTA, 2022b);(NIST, 2020b);(NIST, 2020a). The NICE Framework is developed by the National Institute of Standards and Technology (NIST) that can be used to provide a common lexicon for describing cybersecurity work, workers, and roles for employers. In NICE, cybersecurity is divided into high-level functions known as categories (7), which are further divided into specialty areas (33) and work roles (52). The Cybersecurity Curricula Designer is a web application that can help education providers to create new programs, and analyze existing study programs according to their content and their reflection of cybersecurity job requirements (SPARTA, 2022b). Hajny et al. (Hajny, Sikora, Grammatopoulos, & Di Franco, 2022) have examined the integration of the ECSF into a curriculum designer and thus it is possible to directly link knowledge and skills with the actual 12 professional profiles on the job market. Their work focuses on pairing knowledge and skills to profiles provided by the ECSF in the context of a curriculum designer tool for students. What their approach to the curriculum design tool lacks is the capability to verify that a curriculum covers all essential topic areas for a specified role profile in cybersecurity.

Clearly, there is a need for further methods and/or frameworks to develop the content and to identify gaps in the courses. *The European Cybersecurity Taxonomy (ECT)* (European Commission Joint Research Centre (JRC), 2021) has been developed by the Joint Research Centre of the European Commission as a tool for categorizing institutions and expertise across Europe. It is based on four dimensions: technologies, domains, sectors, and use cases. This taxonomy provides clearer categorizations of topics that are necessary for cybersecurity skills, and can be used in content design. The ECSF framework and the European Cybersecurity Taxonomy can be enriched by including external resources, e.g., the Cyber Security Body of Knowledge (CyBOK) (University of Bristol Cyber Security Group, 2021). In this paper, we have utilized the domains of the ECSF and the ECT as the set of different aspects and themes within the umbrella term of cybersecurity.

PLANNING FRAMEWORK FOR CYBERSECURITY CURRICULUM DESIGN

The motivation for our Planning Framework is to help universities to design cybersecurity curricula that successfully delivers the necessary key knowledge and competences for each role profile based on a European standard, rather than NICE or the ACM curriculum guideline for cybersecurity (ACM, 2017), which are based on the US perspective and/or are lacking operational aspects that are rooted in industry. It also implements the key goals of the ECSF: to create an understanding between supply (universities) and demand (industry) in Europe on common terminology, key skills, knowledge and competences. Finally, it enables universities to educate future professionals for roles in proportion to industry demand.

Mapping course content and knowledge areas

The overall process for curriculum evaluation and design is illustrated in Figure 1. Mapping the existing course contents to the ECT categories shows which topic areas are already covered, and also how well the courses cover the whole field of cybersecurity. For a more detailed assessment and overall process development, weights can be added to the mapping based on course level (e.g. basic, intermediate or advanced) and type (e.g. practical vs. theoretical). The assessment of the course content and matching to taxonomy categories is done based on

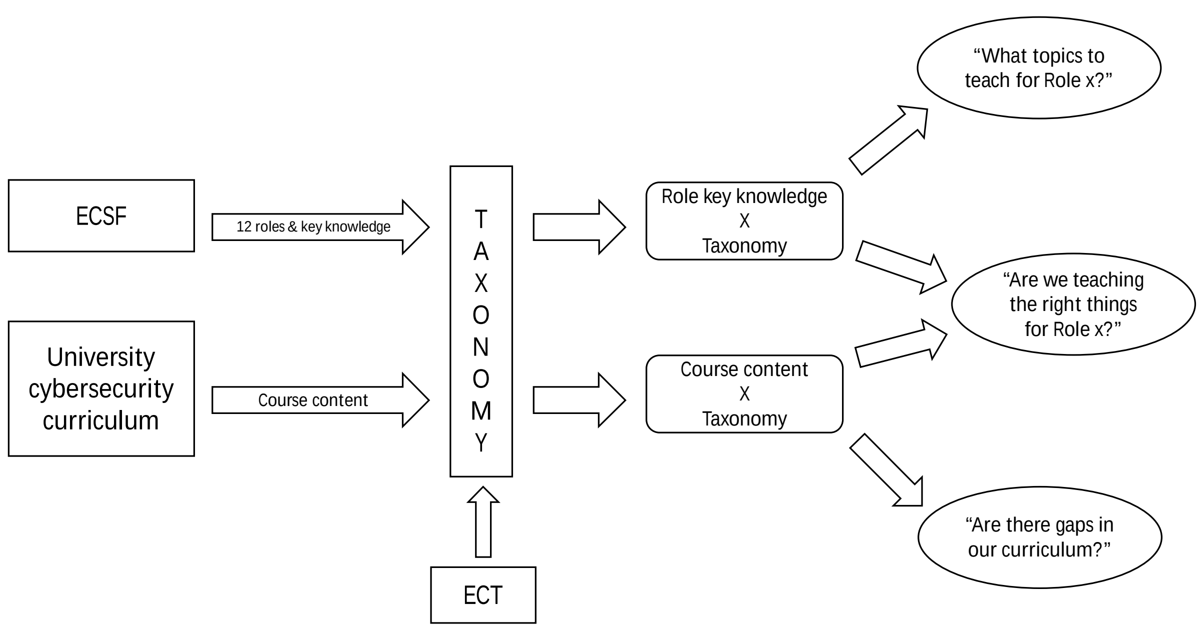

Figure 1. The overall process for incorporating the ECSF roles and key knowledge, ECT taxonomy and university cybersecurity curriculum.

course contents, learning objectives, and an estimation by the responsible teacher.

The mapping between role key knowledge and ECT taxonomy entries is performed next. This process is role dependent, as the perspective on cybersecurity of each role varies depending on the focus, e.g. (attack/defense) and/or abstraction level (hardware/software/architecture/legal).

Each key knowledge entry is matched to taxonomy items by relevance, taking into consideration the differences in focus mentioned above. The result is a nonempty set of matches between knowledge entries and taxonomy items. If the result set is empty, it implies no relevance between the key knowledge and *any* aspect of cybersecurity. This, in our opinion, should not happen when we are considering key knowledge for cybersecurity professionals. This assessment is based on academic and industry experience of the authors.

This process is illustrated in Figure 2. On the left is a general mapping between ECST CISO role's key knowledge areas and the taxonomy. On the right is a mapping between the security management and governance categories of the ECT and a subset of courses offered at the UTU's Department of Computing.

The mapping is challenging to perform due to the size of the resulting spreadsheet. There are twelve roles with between 4 and 15 key knowledge items, each of which need to be mapped to 154 taxonomy entries. We found the most practical way for this mapping to be printing the table on A3 paper and assembling it physically on a large whiteboard (see Figure 3). After the connections between courses and key knowledge areas have been formed via the taxonomy, we can cross-reference between course content and desired knowledge for a specific role through the taxonomy mapping.

		3.1.10. Security management and governance			
		Standards for Information Security	Governance aspects of incident management, disaster recovery, business continuity	Techniques to ensure business continuity/disaster recovery	Compliance with information security and privacy policies, procedures, and regulations
Role	CISO				
CISO	Cybersecurity policies	X	X	X	X
	Cybersecurity standards, methodologies and frameworks	X	X	X	X
	Cybersecurity recommendations and best practices		X	X	X
	Cybersecurity related laws, regulations and legislations		X	X	X
	Cybersecurity-related certifications				
	Ethical cybersecurity organisation requirements				
	Cybersecurity maturity models				X
	Cybersecurity procedures				
	Resource management				
	Management practices		X	X	
	Risk management standards, methodologies and framework		X	X	

	Course 1	Course 2	Course 3	Course 4
3.1.9 Network and Distributed Systems				
Network security (principles, methods, protocols, algorithms and technologies)			X	X
Distributed systems security				
Managerial, procedural and technical aspects of network security				
Requirements for network security			X	X
Protocols and frameworks for secure distributed computing				
Network layer attacks and mitigation techniques			X	X
Network attack propagation analysis				X
Distributed systems security analysis and simulation				
Distributed consensus techniques				
Fault tolerant models				
Secure distributed computations				X
Network interoperability				
Secure system interconnection				
Privacy-friendly communication architectures and services (e.g. Mix-networks, broadcast protocols, and anonymous communication)				
Network steganography				
3.1.10 Security Management and Governance				
Risk management, including modelling, assessment, analysis and mitigations	X	X	X	X
Modelling of cross-sectoral interdependencies and cascading effects	X			
Threats and vulnerabilities modelling	X	X		
Attack modelling, techniques, and countermeasures (e.g. adversary machine learning)	X	X		

Figure 2. Mapping of ECST role key knowledge (left) and existing course content (right) to the ECT taxonomy.

Figure 3. The mapping between ECSF role key knowledge and the ECT entries.

Evaluation

Once the above mapping is complete, we can cross-reference between the key knowledge required in ECSF defined industry roles, and the content of a cybersecurity curriculum, as both are mapped to the ECT. Through this mapping, we can directly assess how well the educational content of the curriculum under evaluation corresponds to the key knowledge defined for a specific role, or a collection of roles, and to identify potential gaps or areas for improvement in course design.

In Figure 4 we assess how well the UTU cyber security curriculum covers the key areas of selected role profiles (Digital Forensics Investigators, Penetration testers, CISOs, and Cyber Incident Responders). The numerical values represent the sum of instances where an aspect of a key knowledge area is covered by courses in the UTU cybersecurity curriculum. The color coding is intended to illustrate the highest (green) and lowest (red) values within each role, while average values are coded as yellow. A key knowledge area that has several matches to different taxonomy entries potentially generates a higher score than one with a single match to

Role	Key knowledge	
Digital forensics investigator	Digital forensics recommendations and best practices	11
	Digital forensics standards, methodologies and frameworks	12
	Digital forensics analysis procedures	7
	Testing procedures	4
	Criminal investigation procedures, standards, methodologies and frameworks	15
	Cybersecurity related laws, regulations and legislations	10
	Malware analysis tools	7
	Cyber threats	4
	Computer systems vulnerabilities	4
	Cybersecurity attack procedures	12
	Operating systems security	37
	Computer networks security	36
	Cybersecurity-related certifications	4
Role	**Key knowledge**	
Penetration tester	Cybersecurity attack procedures	11
	Information technology (IT) and operational technology (OT) appliances	16
	Offensive and defensive security procedures	14
	Operating systems security	39
	Computer networks security	44
	Penetration testing procedures	9
	Penetration testing standards, methodologies and frameworks	10
	Penetration testing tools	7
	Computer programming	19
	Computer systems vulnerabilities	9
	Cybersecurity recommendations and best practices	17
	Cybersecurity-related certifications	4

Role	Key knowledge	
CISO	Cybersecurity policies	61
	Cybersecurity standards, methodologies and frameworks	55
	Cybersecurity recommendations and best practices	36
	Cybersecurity related laws, regulations and legislations	46
	Cybersecurity-related certifications	7
	Ethical cybersecurity organisation requirements	16
	Cybersecurity maturity models	30
	Cybersecurity procedures	13
	Resource management	30
	Management practices	33
	Risk management standards, methodologies and framework	34
Role	**Key knowledge**	
Cyber Incident Responder	Incident handling standards, methodologies and frameworks	22
	Incident handling recommendations and best practices	16
	Incident handling tools	13
	Incident handling communication procedures	16
	Operating systems security	74
	Computer networks security	66
	Cyber threats	17
	Cybersecurity attack procedures	10
	Computer systems vulnerabilities	13
	Cybersecurity-related certifications	4
	Cybersecurity related laws, regulations and legislations	5
	Secure Operation Centres (SOCs) operation	18
	Computer Security Incident Response Teams (CSIRTs) operation	18

Figure 4. Evaluation of UTU cybersecurity curriculum contents matching against four selected roles in the ECSF through matching key knowledge to course contents.

a taxonomy entry. Therefore, the scores are not comparable between roles, as the same key knowledge can have different meanings for different roles, due to the individual mapping of role key knowledge to taxonomy entries.

From the results we observe that our strengths are in computer network and operating system security, which are the strongest areas for three out of four roles. This is an expected result, as many of our existing courses focus on these areas. Similarly, for the more managerial CISO role, our courses provide a good knowledge of policy, standards and recommendations. This is also an expected result. On the weaker aspects, the evaluation confirms our initial assessment that the program lacks hands-on procedures for incident responders, forensics investigators and penetration testers. Observed knowledge gaps for these roles include cybersecurity procedures, vulnerabilities from the defensive perspective, use of tools, ethical issues, and cybersecurity certifications.

For example, we can observe that for forensic investigators, the category "Cyber threats" receives a score of 4, while for incident responders the score is 17. This does not mean that the curriculum does not cover cyber threats, but rather that the specific aspects of forensic investigators are not covered. Given the strong signal from previous research that more cyber incident responders are needed, improving the educational content in this category would be worthwile.

DISCUSSION

The global shortage in cybersecurity professionals that has been identified by many researchers and analysts can be further pigeonholed into more precise demand for new talent in specific roles. The ECSF roles provide the connection between industry needs and cybersecurity education planning. By leveraging the ECSF it is possible to design cybersecurity education with the desired impact on the level of an individual programme, a single university, or a group of universities seeking to coordinate their educational profiles. The reason for incorporating the ECT in the process is to use a common European foundation and understanding of cybersecurity domains at the core of the framework.

Curriculum design is not an exact science, and we do not advocate that it should only follow mechanical procedures and constraints. The expertise and intuition of the teacher designing the curriculum and the capability to leverage limited resources for the best possible outcome remain vital to a successful cybersecurity education programme. However, we do advocate the use of well-defined processes and frameworks to both help with the design of new a curriculum, and to act as a sanity check for existing ones. Our framework provides a systematic approach to verify and control that an existing curriculum contains the necessary topics at the necessary depth for graduates to operate in industry.

A key finding from the curriculum analysis is that cybersecurity certification is a core knowledge and competence in many roles, but current curricula are not sufficient to provide certifications to university students. University-industry cooperation can help to provide technology or vendor-specific certifications to students (Hakkala & Virtanen, 2012), but given the importance of certifications in the field and the emphasis on certifications in life-long learning in cybersecurity, universities should be able to provide both more information on certifications to students, and perhaps even early career certifications (Majanoja, Hakkala, Virtanen, & Leppänen, 2023).

We also observed that in our opinion, certain roles lacked key knowledge areas: those working in a CISO or cybersecurity risk manager role can benefit from the legal aspects of cybersecurity, but this was not included as a key knowledge area. Another observation we made was that some role profiles can benefit from multidisciplinary degree programmes or even complete second degrees, as for example cyber legal, policy and compliance officers are more likely than not to be lawyers rather than engineers or computer scientists. This provides multidisciplinary universities an edge in providing education that can meet the demands of today's world.

Future work. For each key knowledge area within a role, the ECSF also defines a competency level based on the e-Competency standard. In this version of our framework, the effects of these levels is not yet considered. It is also open to debate how universities can provide deeper competences (up to e-4 and e-5), which in practice requires extensive work experience and practice to attain. The perception of industry on what the competence level of fresh graduates should be, and what is realistically attainable in higher education do not necessarily match. There is existing research on industry expectations based on job advertisements, but as the nature of the job market varies between countries, a holistic view is difficult to form. A mapping of industry actor expectations and requirements to the framework established in this paper will be explored in future research.

Through our framework is is possible to integrate the CDIO standards and practices into the core of curriculum development. Through the integration of e-CF we can identify key competences in cybersecurity and map them to course content. Similarly we can identify core CDIO skills and principles from these competences and integrate them to the curriculum already at the design phase, thus fulfilling the goals of standard 3. After we have identified these skills and principles, the framework facilitates synergies between industry and universities by integrating industry partners into teaching those skills to students in the necessary context.

When implementing the curriculum in the form of courses, active learning methods can be conveniently mapped to individual topics, competences and themes from the framework. The advantage of our approach is that when there is a clear mapping between competences, topics and roles, the learning methods for conveying subject information according to CDIO principles are easier to determine.

The integration of CDIO standards into the framework provides the opportunity to thoroughly analyze each educational topic and determine the best way to arrange the teaching for each course. Having such a structured tool for curriculum design also provides a tool for communicating to stakeholders and implementing forms of continuous follow-up and improvement of the curriculum.

The accumulation of competences is also influenced by the organization of the teaching: how much is hands-on practice with industry standard tools and programs, and how much is purely theoretical? In Finland, universities of applied sciences have traditionally focused more on tool-specific hands-on exercises and problem-based learning, while university teaching is more grounded in theory, complemented by more generic practical exercises. However, the issues identified in cybersecurity higher education are present in both. More research is needed in this area.

When discussing higher education policy at national level, the level of abstraction is above individual courses or even curricula. In public discussion, the focus is on "cybersecurity professionals" and their perpetual shortage. Our aim is to use this framework in a national development project on cybersecurity capabilities and the division of responsibilities between different universities in Finland. A project for this purpose, funded by the Ministry of Education and Culture, has started in late 2022. Our contribution to this project will be based on the framework presented in this paper, enhanced with the aspects of the e-Competency standard.

CONCLUSION

The goal of the curriculum design framework is twofold. First, it facilitates the design of better cybersecurity curricula by providing a tool with which we can verify that an existing curriculum indeed is focused on the desired aspects, technologies and topics that correspond to the desired professional profile of graduates from the degree programme. Second, it facilitates a systematic approach to building a new cybersecurity education programme at university level that provides graduates with a professional profile desirable to the wider industry.

The framework presented in this paper serves as a starting point for defining education profiles for universities. Once the desired education profiles have been selected, the framework can be used to analyze an existing curriculum to see how well it meets the requirements of each professional role profile, and to identify potential gaps in content that need to be addressed. The content, structure, and organization of studies can vary considerably between universities and degree programmes. This framework makes it possible to benchmark cybersecurity degree programmes against those of other universities.

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A CHALLENGE BASED LEARNING COMMUNITY FOR HYDROGEN DEVELOPMENT AND APPLICATION

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ABSTRACT

The University of Twente, Saxion University of Applied Sciences, ROC of Twente (vocational education), centre of expertise TechYourFuture and the H_2Hub Twente, in which various regional hydrogen interested corporations are involved, work together to shape a learning community (LC) for the development of innovative hydrogen technology. The cooperation between company employees, researchers and students provides a means to jointly work on solutions for real-life problems within the energy transition. This involves a cross-chain collaboration of technical programs, professorships and (field) experts, supported by human capital specialists. In the LC, a decentralized hydrogen production unit with storage of green hydrogen is designed and built. The main question for this research is: how can the design and construction process of an alkaline electrolyzer be arranged in a challenge based LC in which students, company employees (specialists) and researchers can learn, innovate, build-up knowledge and benefit?

In this project the concept of a LC is developed and implemented in collaboration with companies and knowledge institutions at different levels. The concrete steps are described below:

1. Joint session between Human Resource and Development (HRD) specialists and engineers / researchers to explore the important factors for a LC. The results of this session will be incorporated into a blueprint for the LC by the human capital specialists.
2. The project is carried out according to the agreements of the blueprint. The blueprint is continuously updated based on the periodic reflections and observed points for improvement.
3. Impact interviews and periodic reflection review the proceeding of the LC in this engineering process.

The first impact interview reveals that the concept of the LC is very beneficial for companies. It increases overall knowledge on hydrogen systems, promotes cooperation and connection with other companies and aids to their market proposition as well. Students get the opportunity to work in close contact with multiple company professionals and build up a network of their own. Also the cooperation with students from different disciplines broadens their view as a professional, something which is difficult to achieve in a mono-disciplinary project.

KEYWORDS

Hydrogen development, hydrogen applications, Learning Communities, engineering, standards: 2, 5, 6, 7, 8, 9

INTRODUCTION

Due to worldwide climate change caused by CO_2 emissions, there is an increasing urgency to change energy systems towards 100% renewable energy. Green hydrogen is a promising renewable energy carrier for transportation, industrial applications, building activities and heat demand. It is produced either from biobased sources or by electrolysis of water using electricity from renewable sources, e.g. next to large wind turbine or solar PV farms, or as part of local or regional energy hubs (Shiva Kumar *et al.*, 2022; Nguyen *et al.*, 2019).
The demand for engineers with electrolyzer and hydrogen know-how is increasing, so there is a need for hydrogen related training opportunities (Tretsiakova-McNally *et al.*, 2017). Learning Communities (LCs) have proven to be a suitable form of training (Corporaal *et al.*, 2021), and it may cover different engineering and societal aspects of hydrogen technology. According to 'The future of hydrogen' (Gül *et al.*, 2019), it is expected that the creation of jobs in manufacturing, installation and maintenance of electrolyzer systems will be increasingly important worldwide. The importance of a potential vocational training based (e-)learning program is stressed, covering different types of fuel cells and applications and targeted mainly at safety, automotive and stationary fuel cells.
During the last 20 years, the Conceive, Design, Implement and Operate (CDIO) initiative has been focusing on bridging the gap between engineering education and the industry's vision for their new employees' skills. According to the CDIO, engineering education should focus on real-world demands in the complete value chain and all skills needed to successfully execute the engineering profession (Crawley *et al.*, 2007). Hence, the CDIO approach is largely based on the idea that students should, during their time at the university, face reality-alike contexts and situations that facilitate learning of professional skills which are very important to prepare students for their future profession. Simulating these settings can increase students' motivation and enhances learning.
The University of Twente, Saxion University of Applied Sciences, ROC of Twente (vocational education), centre of expertise TechYourFuture and the H_2Hub Twente work together to shape a challenge based LC, where a decentralized production unit with storage of green hydrogen is designed and built.

In section 2, a theoretical background of challenge based LCs is presented. The theory is used to develop a blueprint for the challenge based LC in the engineering project HYGENESYS (section 3). The first impact interview indicates that the LC is functioning well and the first conclusions that can be drawn, are presented in section 4 and 5 of this paper. The paper ends with section 6 by expressing some future lines of research.

SETTING UP AN EFFECTIVE LC

LCs are public-private partnerships in which learning, working and innovation merge into a hybrid learning environment. Although there is a great diversity of manifestations of LCs, a number of core dimensions can be specified (West *et al.*, 2017). A 'community' is seen as a group of people who interact with each other around a common issue or interest. Participants in a LC work together collectively on a meaningful challenge to build on already existing knowledge, and thus learn at the individual and group level (Blackshaw, 2010). The interaction between participants is promoted if, on the one hand, they feel interdependent and responsible for the problem, and on the other hand they feel safe and familiar in the group. The 'learning' in LCs is seen as a negotiation process between participants to increase knowledge and skills on a particular subject. Through knowledge sharing, critical and reflective surveys, collective and individual knowledge is increased (Stoll *et al.*, 2006). This 'learning' is necessary to be able to respond to rapid changes and to be proactive in innovation processes. In addition, learning, working and innovation are seen less and less as purely individual and isolated processes, but as a collaborative, co-creating and context-rich process in which these aspects come together. In this context, the quadruple helix is also referred to in which companies, knowledge institutions (students and researchers), governments and citizens play an (active) role in creating new knowledge, technologies, products and services (MacGregor *et al.*, 2010).

To make the proceedings of LCs visible at every level, the conceptual framework of 'value creation', developed by Wenger *et al.* (2011), is used. This framework has been applied in various sectors and lends itself well as a basis to provide insight into the great diversity of possible returns: immediate, potential, applied, realized and transformative returns. The stakeholders have their own motives to participate in these LCs. To tackle social issues and make optimal use of the up-to-date knowledge, skills, attitudes, expertise and talents of the individual participants, each of these stakeholders are important. Potential returns for these stakeholders can be described as follows:

Companies
Participation in LCs and the acquisition of new knowledge and skills that go with it, enables the introduction and implementation of innovative ideas, thereby improving the performance of an organization (Crook *et al.*, 2011). Participation in a LC not only leads to better trained employees; it can also contribute to the development of an organization's learning culture, which is an important predictor of innovative behavior and performance (Sung *et al.*, 2014). Furthermore, participation in a LC also increases cross-boundary cooperation, which can improve the competitive position of that company.

Knowledge institutes
Learning environments that are co-created by both educational institutions and companies can become nodes in the sector and/or region (Zitter, 2021). The revenues of LCs for these educational and knowledge institutions are twofold. On the one hand, LCs contribute to the generation and unlocking of knowledge, or rather the effect on professional practice, education, professionalization and knowledge development. On the other hand, LCs offer students the opportunity to be educated closer to or together with companies. By working on complex problems with practice, students develop adaptive ability, self-management and collaboration; competences that are important in a changing world (Van Huffelen-de Boer, 2019). These authentic assignments motivates students, in accordance to Jaca *et al.* (CDIO, 2021).

Citizens
The role of civil society and citizens is especially valuable for strengthening social innovations in regions. Social innovations can be defined as the development and implementation of new ideas (products, services, and models) to meet social needs and create new social relationships or collaborations. The role of civil society is crucial in addressing climate change and strengthening ecological innovations. Citizens as consumers are needed to represent the

demand-side perspective of innovations. Civil society is an important stakeholder in regional innovation process and developments of innovations addressing sustainable development goals.

Government institutions
Governments have a great interest in solving complex social issues and for that reason governments subsidize projects that try to find solutions. LCs offer government agencies the space to look at solutions outside the usual systems (Schütz *et al.*, 2019).

In 2019, the Dutch national top sectors (*Topsectoren*) program joined forces in an action-oriented *Roadmap Human Capital 2020-2023* with the mission: 'a future-proof workforce as a condition for a flourishing economy and a positive social dynamic'. Part of the programming of this Roadmap is the weaving of LCs into the Multi-year Mission-driven Innovation Programs (MMIPs) of the top sectors and research programs of the Dutch Organization for Scientific Research (NWO). The concept of LCs is seen as the solution to connect learning, working and innovation. In the Roadmap, LCs are seen as an umbrella term for various forms of inter-organizational collaboration such as Living Labs, Field Labs, hybrid learning environments, professional work- shops, innovation workshops and Centers of Expertise (Topsectoren, 2019).

LCs aim to contribute to solutions for major social or technological issues. To achieve this goal, proceedings must also be realized at underlying levels, such as revenues for organizations and individuals. To provide insight into this layering of revenues, a distinction, as shown in figure 1, is made between proceedings at micro level (individual returns), meso level (returns for organizations and knowledge institutions) and macro level (social returns) (Schipper *et al.*, 2022).

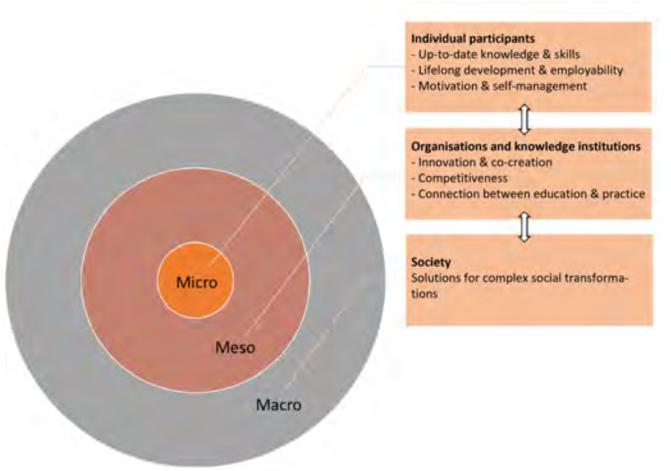

Figure 1. Schematic representation of LCs revenues at the micro, meso, and macro levels (Schipper *et al.*, 2022, p. 20)

The challenge based LC for the HYGENESYS project delivers revenues on micro, meso and macro scale for the involved organizations, educational and government institutions. The developed LC is based on some key elements as identified in a previous research project (Corporaal *et al.*, 2021):

- **Multidisciplinary work**: Learning within the LC is basically a social process, but is closely connected with individual learning. Individual stakeholders bring in their own expertise but there is a joined responsibility for the final deliverables. A facilitator supports the three most important aspects of team learning (team activity, team reflexivity, boundary crossing).
- **Shared ownership**: Learning and working is situated and integrated with daily social practice. The challenges are within the working domains of the stakeholders and results are directly

relevant and applicable. Activities can be carried out within the chosen timescale.

- **Facilitating meetings between stakeholders, experts and students**: The LC fulfills the three main basic psychological needs for intrinsically motivated participants. These needs are connectedness, autonomy and self-management. Participants feel confidence (self-efficacy / team-efficacy) and competence, both through the support of the organization and through the facilitation offered. Learning, working and innovating within the LC is self-managing and agile. Scrum is the preferred methodology. The joint process is socially regulated, where the individual process is self-directed, possibly through co-regulation.
- **Organizing effective ways of knowledge sharing to bring the proceeds of LCs to society**: The LC focuses on making the learning outcomes more sustainable and continuing the LC itself. The LC results in a way-of-working (for instance sharing knowledge) and is integrated in following projects and co-operations.

Evidence-based research about work design, workplace learning, team learning, self-directed learning and motivation translate these key elements in design principles for the LC blueprint (Corporaal, 2019). In this project the development and construction of the electrolyzer (project HYGENESYS) is translated into a macro, meso and micro LC based on the mentioned design principles in which students, professionals and stakeholders work in teams together on challenges from the HYGENESYS project plan.

DEVELOPMENT OF THE CHALLENGE-BASED LC BLUEPRINT FOR THE HYGENESYS PROJECT

Currently, there is still limited knowledge available both in industry and at knowledge institutes about the realization and application of hydrogen production equipment at larger scale. The technological development of constructing a robust and safe hydrogen electrolyzer is a challenging multi-disciplinary engineering task. It consists of several steps, ranging from global system engineering towards drafting a detailed design, followed by manufacturing, testing and verification. This development is well written in the HYGENESYS projectplan, where all the work packages and challenges are described. These challenges are carried out by several companies and knowledge institutes within the LC. Figure 2 shows work package 2 (out of 5), the involved challenges and companies and the concept design of the LC.

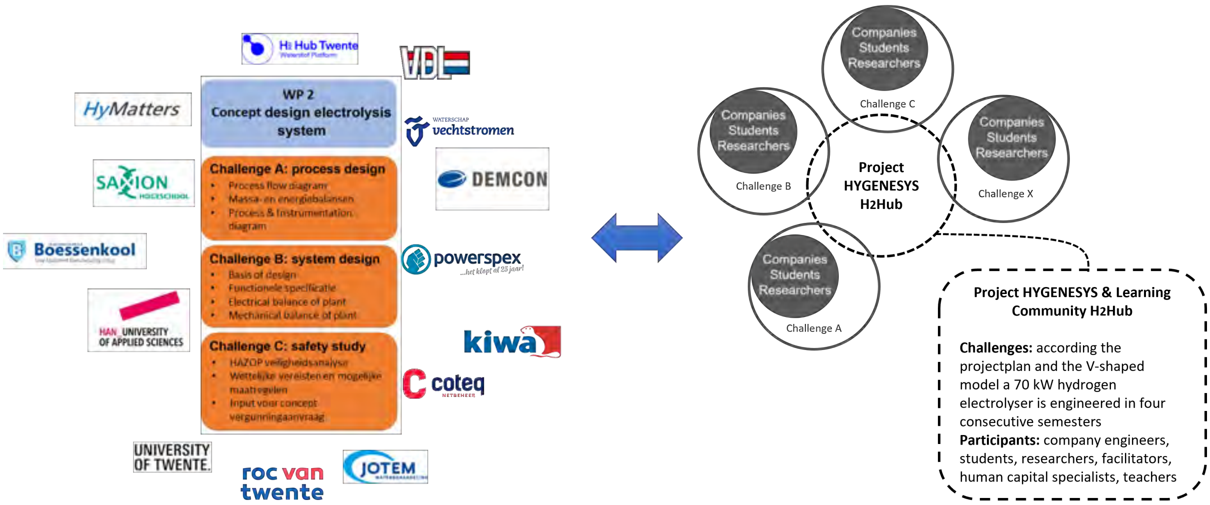

Figure 2. Work package 2 and consortium from the HYGENESYS project (left) versus concept design LC (right) (Corporaal *et al.*, 2021).

The consortium of companies and knowledge institutes is a mix of specialists and generalists, each with different interests and ideas. In order to come to an operational electrolyzer system, the process was split into several manageable challenges, linked to specific companies, researchers and students that have the appropriate skill set to tackle the task. For work package 2 these (sub)challenges are shown in figure 2 (left), resulting in the design for the challenge based LC (right).

The main question for this research is: how can the design and construction process of an alkaline electrolyzer be arranged in a challenge based LC in which students, company employees (specialists) and researchers from the three educational institutions can learn, innovate, build- up knowledge and benefit?
An important aspect within this LC is to obtain commitment from all involved stakeholders and to formulate clear working agreements. This should lead to a situation where all partners benefit from the project. To accomplish this the following steps were taken:

1. Joint session between HRD specialists and engineers/researchers to explore the important factors for a LC. The results of this session will be incorporated into a blueprint for the LC by the human capital specialists.
2. The project is carried out according to the agreements of the blueprint. The blueprint is continuously updated based on the periodic reflections and observed points for improvement.
3. Impact interviews and periodic reflection review the proceeding of the LC in this engineering process.

The developed model for the LC that includes the key elements described in Section 2 is represented in figure 3, in which (multi- or interdisciplinary) LC teams, learning paths of students and professionals and expertise platforms are connected. The LC teams work in an equal collaboration on integrated complex issues and consist of multiple stakeholders, in which the field of work, education and research are always represented.

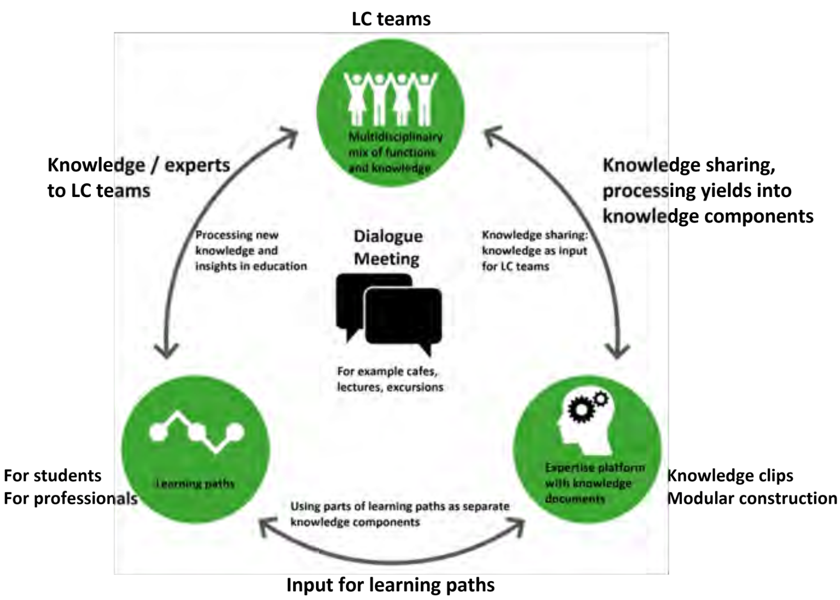

Figure 3. Model for developing the LC for the HYGENESYS project; the purpose and deliverables of a LC (van der Laan *et al.*, 2022)

The concrete steps towards the LC blueprint for the HYGENESYS project are described below:

1. Participating companies from the project HYGENESYS are approached for a LC design session. In this session, HRD specialists and engineers/researchers have an open discussion to

retrieve how the business community views the development and how knowledge institutes involve students and researchers in the process. Each involved participant is given the opportunity to express their view on the way of cooperation within the LC. The results of the design session is incorporated into a blueprint for the LC by human capital specialists.

2. During the kick-off of the HYGENESYS project, the main goal is to form the LC for the challenges, make work agreements and streamline expectations. The most important indicated attention points are project focus, concrete results or output and ways of communication.
Based upon the design principles, the development session with stakeholders and the kick-off meeting, the concrete blueprint for the challenge based LC for the HYGENESYS project was developed. Table 1 shows this blueprint and summarizes the ideal settings for the most important parts.

Table 1: Blueprint for the HYGENESYS LC

Part	**Elaboration**
Challenges central	The LC starts with two major challenges. Divide big challenges into smaller parts (which are manageable, following the partial outcomes of each challenge). In addition, also organize plenary meetings (e.g. 4 times a year) to facilitate knowledge exchange between the challenges (all participants are present). Goal: small solutions contribute to the big challenges
Participants	Number of participants can vary per group of the (sub)LC, depending on the knowledge that is required; determined in advance. Starting from max 8-10 persons per LC.
Frequency of meetings	Per (partial) LC a period of 4-5 months to work (± 20 meetings), with a weekly or biweekly physical meeting of 3-4 hours. Goal: knowledge sharing and monitoring progress
(Learning) activities	In between the LC meetings, various activities take place; e.g. visits to different companies, suppliers or other places where H_2 is used. Or to test things at the test location.
Facilitator	Preferably someone who has no knowledge /experience with the subject; or in collaboration with a technical manager per challenge.
Consortium guidance	Internal and external communication, both technical target group and 'the ordinary person'. Time planning and all practical matters. Confidentiality versus openness

The blueprint is a starting point of the collaboration within the LC, but will be reviewed and improved during the course of the HYGENESYS project.

IMPACT AND PROGRESS OF THE LEARNING COMMUNITY

The project HYGENESYS and the challenge based LC started in September 2022 and will continue in four consecutive semesters till September 2024. In the first semester (September 2022 till February 2023) two challenges have started. Although the project is currently still in an early stage, the progress and especially the impact is already noticeable:

Figure 4. Progress and impact of the challenge based LC. *Left*: discussing work agreements per challenge during the kick-off, *middle*: the LC at work, *right*: sharing the progress and aligning challenges at a periodical consortium meeting

• **Kick-off HYGENESYS**: During the kick-off, the full consortium (students, companies and knowledge institutes) was present to discuss the blueprint and make working agreements suitable for the challenge involved (see figure 4, left). Coordinators of the challenges align the expectations of the stakeholders; students were introduced and specific agreements were made about planning and focus.
• **Challenges at work**: The two challenges (see figure 2) follow a rhythm suitable for the activities and deliverables. Challenge AB focusses on the global system design. Within this challenge, frequent meeting, discussion and knowledge sharing is necessary. The participants meet every Friday morning physically at the location of the H_2Hub in Almelo, The Netherlands for an intensive discussion and work session (see figure 4, middle). Each meeting starts with a scrum stand-up featuring the progress during the week, the planning for the coming week and questions or difficulties which were encountered. These short cycles of intervision enlarges involvement of the companies. Companies are encouraged to be present at these sessions and actively join the students in their work. The companies are involved via either junior or senior engineers and especially the junior employees gain knowledge and skills via this methodology.

Challenge C deals with the safety aspects of the engineering process. These activities are much broader and will continue during almost the whole duration of the HYGENESYS project. Physical progress meetings are planned every month, are supervised by the coordinator and cover more work packages over a longer period of time. Safety and process engineering will eventually interact more strongly and meetings of both the AB and C challenges will be combined in the near future.
• **Periodical consortium meeting**: Every 10 weeks a plenary meeting is organized where the companies, knowledge institutions, students and LC coaches are invited at the H_2Hub location to discuss the results of the challenges and to consider the overall state of affairs within the project (see figure 4, right). This is also the opportunity to make strategical decisions in agreement with the whole consortium.

The impact that the challenge based LC already has, is recently evaluated during a first impact interview. During an open discussion, different stakeholders from the consortium reflected on the established LC. Table 2 shows the most important and striking remarks of the involved stakeholders from the different challenges.

Table 2: Impact interview for progress challenge based Learning Community

Stakeholder	**Impact**
4th year student Chemical Engineering	The concept to connect knowledge institutions, companies and students in this form, is new to me. Especially that you really operate and participate among the involved company specialists. To come in contact with so many different companies from different sectors is stimulating and would not have been possible otherwise.
Researcher University of Applied Science	In this LC there is an open attitude to share knowledge. There is a lot of exchange between the students and the structure makes students understand that their assignments are connected. This invites mutual sparring, an important learning process for students. In parallel to developing practical knowledge about hydrogen generation systems, this LC inspires to achieve research goals.
Associate professor University of Applied Science	In addition to working towards a final solution in a multidisciplinary group, the LC also brings a new focus to it: how do we learn from each other in this project? This equal cooperation aspect is already anchored to some extend in the Dutch working and consultation culture. The LC is an organically developing ecosystem with progressive insights that you cannot foresee in advance.
Senior Engineer company	The consortium ultimately develops an end-product together, and shares experiences to approach something like this from design and construction to the test and execution phase. The participating companies also learn from each other. Furthermore, expanding the company's network and taking a position on the labor market is important. If you are engaged in innovation, you run the risk of working in a cocoon. A LC gets you out of that. Weekly work sessions are a critical success factor and the trick is to celebrate our interim achievements with each other!

Chief Operational Officer company	The hydrogen market is still in its infancy and to achieve a viable market, a complete chain of production, storage, distribution and use has to be built. Everyone is needed to contribute to this, ranging from knowledge institutions and companies to students. As a company sharing knowledge externally in a LC to develop that market together, is necessary.
CEO H_2Hub and client	Working together with external partners is not new, but this collaboration based on a challenge-based LC is. In order to arrive at a prototype decentralized electrolysis system, developing knowledge together in many complex subfields is necessary. In the LC, the participating companies not only mix with, but also truly involve the students. That is what makes this LC unique. It is a kind of joint journey where the project sometimes has to turn left and sometimes right.
Project manager HYGENESYS	The challenge-based LC is a learning and innovation methodology in which researchers, students and company employees work together equally on (sub)issues in relation to the HYGENESYS project. Within this, they constantly inspire each other to innovate and create together. A research cloud environment is used with all relevant knowledge and data and is completely open to everyone who participates in the project. In addition, e-mail and practical WhatsApp groups for each challenge are used, which works very effectively.
Specialist Human Capital	In order to come to a solution, such as for this hydrogen application, a first step is the recognition of the need of both companies and knowledge institutions as well as that of students. It is a permanent learning process in which you support each other, question and help each other to move forward. In that way, all the prerequisites are met that belong to forming a community. As a result, the participants feel connected and involved. The core of a LC is that all participants are equal.

Note: the feedback in table 2 is all very positive. However, it is expected that it is still too early in the process to define any points for major improvements. These will probably emerge once a second batch of students goes to work. Then, difficulties related to knowledge transfer, planning and availability of students could be encountered.

There are several conclusions from the impact interview which are well in line with the design principles described in this article and the observations described in literature.

Firstly, the 4th year student stresses the importance of ’authentic assignments’ and indicates that ’LCs offer students the opportunity to be educated closer to or together with practice’. The researcher from Saxion University of Applied Sciences notices that the ’students develop adaptive ability, self-management and collaboration’. This output of the interdisciplinary student-community is also observed by Mejtoft et al. (CDIO Conference, 2022).

Furthermore, the involved companies express the need to share knowledge and collaborate with other companies in order to make progress in hydrogen technology and development. Working within a LC ’increases cooperation across the boundaries of their own organization’, while on the other hand joining the LC ’can improve the competitive position of the company’.

Thirdly, the LC gives results on micro, meso and macro scale:
- At micro scale motivation and management is highly self-regulated, there is build-up of open-access knowledge and ’*lifelong development of company employees*’.
- At meso scale co-creation and connection between education and practice is clearly visible (for instance as mentioned by the CEO of the H_2Hub)
- At macro scale the development of a LC as organic ecosystem between students, companies and knowledge institutes in an equal work environment can be used for further initiatives in different fields.

Fourthly, the specialist around Human Capital observes that all prerequisites are met for having a successful LC, where the ’*participants feel confidence (self efficacy / team efficacy) and competence*’. In the LC there is involvement, connectedness and equalness.

Lastly, working from a digital cloud environment and having both formal and informal contact between participants, leads to ’*shared ownership*, where ’*results are directly relevant and applicable*’ for each partner within the consortium.

CONCLUSION

The energy transition requires new skills of people and for training of these skills, and the LC approach is a new concept where students work together with professionals on a real challenge. To set up a good working LC with mutual ownership between students, company specialists and researchers, theory and experience within this work conclude the following guidelines:

- Link challenges that are recognizable and attractive to all participants to the LC. A multidisciplinary and relevant project for companies is important, this ensures intrinsic motivation for all stakeholders.
- Create an equal substantive collaboration between the three participating stakeholders. This means that all participants learn from each other equally, the best condition for open cooperation.
- Create good knowledge transfer moments as participants in the LC gradually change and organize a stable and clear system for mutual communication and data storage in the LC.
- Physical contact moments to work with each other and consult around the project or challenges are essential for mutual involvement. These give motivation and energy to go further.

Although these guidelines work well within the presented engineering project and location, the authors would like to stress that setting up a LC needs also customization to the encountered situation.

FUTURE WORK AND CHALLENGES WITHIN THE LEARNING COMMUNITY

Future work will consists of a more elaborate evaluation and an applied science publication for similar situations to build up a LC for a technical project in the engineering domain.
The project HYGENESYS will continue on the development of the electrolyzer and the new work package 3 (from February till September 2023) involves a more specific and detailed engineering focus. Within the LC a few important aspects are faced:

- A new work package means new challenges within the LC. Coordination of these challenges is carried out by one of the consortium partners and will probably result in a change in work dynamics. It will take time and effort to deal with this new dynamics.
- The project HYGENESYS follows four consecutive semesters from the curricula of the students. Progress of the engineering development and the dynamics of the LC will strongly depend on the uncertain forming of a new group of (internship or graduation) students from different disciplines and/or knowledge levels. It is also a challenge to involve the vocational education, where the research focus is less important.
- It will take time and effort to arrange a good transfer between old and new students and for new students to get up to speed.

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CASE-BASED LEARNING IN COLLABORATION ACROSS UNIVERSITIES TO ENHANCE STUDENTS' UNDERSTANDING OF SUSTAINABILITY

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ABSTRACT

Focus on sustainability is increasing in engineering and management education, businesses, and the larger society. In order to cope with sustainability challenges, more holistic pedagogies and practices that foster interdisciplinary and transdisciplinary ways of thinking are needed. Thus, this exploratory paper aims to provide insights into developing a master's-level course module on sustainability in business networks by using active learning through case-based teaching together with collaboration among three Nordic universities (NTNU, Vaasa, and Chalmers). The paper illustrates the multiple facets of designing, implementing, and evaluating three-party collaborative case-based learning based on an active learning approach that enhances students' learning and performance. We conclude that the students are actively involved and learn better with case-based learning and can further empathize and associate with the case contexts. This can be achieved through engagement in cross-border collaboration, a mix of student backgrounds, flexibility in choosing cases, and clarity in case materials. Additionally, we encourage teachers to use a combination of innovative active learning methods to promote students' in-depth understanding of complex sustainability-related challenges.

KEYWORDS

Case-based learning, Active learning, Online learning, Sustainability, University collaboration
Standards: 7,8

INTRODUCTION

Increasing attention has been paid to sustainability in engineering and management education (Figueiró et al., 2022; Malmqvist et al., 2022; Cullen, 2017), businesses (Kiron, 2012; Fontana et al., 2022), and the larger society (Brundtland, 1987). As a result, universities and university programs have worked to integrate sustainability into their curricula (Stough et al., 2018; Howlett et al., 2016), and many courses have separate modules focusing on sustainability (Holt, 2003; Rusinko, 2010). However, sustainability encompasses several aspects and thus needs to be integrated into a wide range of courses so as to prepare future engineers (Thürer et al., 2018) and business managers (Eizaguirre et al., 2019) for their professional careers, regardless of the sector (Howlett et al., 2016; Wamsler, 2020).

Higher education is pluralistic, and universities offer a broad selection of subjects, programs, and courses and are committed to developing students for a sustainable future (Gramatakos & Lavau, 2019). Sustainability topics have proliferated in science, technology, engineering, and mathematics (STEM) education and have been identified as a particular area for teaching and learning. However, a multidisciplinary approach is required, as STEM subjects in isolation cannot provide the depth needed to foster sustainability knowledge (Rogers et al., 2015). Management education and business schools have also seen substantial growth in interest in sustainability and sustainability topics (Cullen, 2017). However, in terms of STEM education, engineers with an eye to sustainability are advised to participate in transdisciplinary activities to develop transdisciplinary knowledge, because traditional engineering programs currently lack such support (Tembrevilla et al., 2023). At the same time, in terms of management and business education, although they have been swift to include sustainability in the curricula, there still remain challenges that must be handled. These challenges are related to the integration of sustainability into the course structure (i.e., as an integrated part versus as an isolated activity) (Figueiró et al., 2022), implementation of responsible and sustainable management (Maloni et al., 2021), the understanding of sustainability (Cullen, 2017), various perspectives on sustainability (wicked) problems (Lönngren et al., 2016; Lönngren, 2017), and how to best convey a sustainable business orientation that fosters a win-win situation for business, society, and the environment (Kolb et al., 2017).

In order to cope with these challenges, more holistic pedagogies (Wamsler, 2020) and practices are needed that foster interdisciplinary (Howlett et al., 2016; Kohn Rådberg et al., 2020) and transdisciplinary ways of thinking, including system thinking (Tembrevilla et al., 2023) and developing capabilities, with the latter defined by Sandri (2011, p. 39) as “holistic sets of attributes and skills that empower graduates to act in differing contexts.” One highly valued and sought-after education track in the Nordic countries lies at the crossroads of technology, management, and economics: university programs under the umbrella of Industrial Economics, Engineering, Management, and Technology. These programs provide a mix of STEM and management education, thus making them cross-disciplinary by design; moreover, systems thinking is ingrained in the management aspects of these programs. Therefore, management courses focusing on how business actors interact, their industrial activities, and the dynamics that are at play in actors’ economic exchanges could be a good site to dig deeper into the contemporary business world that is striving to become more sustainable. Moreover, novel teaching approaches that prepare students to make decisions, think critically, and improve their analytical skills are sought-after (Bezanilla et al., 2019).

The case method is widely used and accepted as a complement to classroom-based lectures (Becheikh et al., 2022). This method includes active learning components based on the notion that students best internalize what they learn by being active (Kunselman & Johnson, 2004).

Druckman & Ebner (2018, p. 359) state that the active component rests on the idea that students "need to bring their knowledge to bear on a case, identify the core problems it presents, and identify key questions that need to be answered." Furthermore, McDonald et al. (2022) argue that active learning strategies (such as case-based learning) assist in enhancing various skills. Nevertheless, Case (2019) argues that it is not necessarily about traditional classroom-based lectures versus active learning components, but rather a combination that focuses on knowledge involving strong conceptual explanations fused with strategies that help foster student engagement.

New approaches to sustainability in education and new ways to frame the teaching environment are imminent. Along those lines, the CDIO syllabus (http://cdio.org/) has been updated to address the "systemic characteristics of societal transformations and the crucial role of engineers in sustainable development" (Malmqvist et al., 2022, p. 23), advocating for a more holistic—i.e., systems-thinking—approach to sustainability, the inclusion of various stakeholder perspectives, and collaboration. In addition, Malmqvist et al. (2022) assert that both the interdisciplinary and international aspects (Säisä et al., 2020) of the CDIO syllabus need to be strengthened.

Overall, we argue that case-based teaching and learning are well-suited for students learning about sustainability, whereby they can help each other, reflect, develop capabilities, and acquire useful cross-disciplinary knowledge post-university. Thus, this exploratory paper aims to provide insights into developing a master's-level course module on sustainability in business networks by using active learning through case-based teaching together with collaboration among three Nordic universities (NTNU, Vaasa, and Chalmers). Building on our aim, the research questions (RQs) were articulated as follows:

- RQ 1: How can we develop a course module focusing on sustainability from a business and management perspective that provides a more holistic/systemic view?
- RQ 2: What are the opportunities and constraints in developing a case-based course module across multiple universities that is based on active learning to enhance student learning?

The structure of the paper is as follows. In the following section, we provide the rationale for developing the course and elaborate on an active learning approach with cases. After that, we provide details on how we approach case-based learning and describe our case-based sustainability module. Next, we describe our method. Finally, we end the paper with a discussion of our findings and some concluding remarks.

FROM RESEARCH TO EDUCATION: DEVELOPING A BUSINESS NETWORK COURSE IN THREE NORDIC COUNTRIES

Courses addressing industrial economics, technology management, and strategic management provide a wide range of subjects, one being the management of businesses in industrial networks. The starting point for understanding industrial networks is that business actors are embedded in networks as a result of their business relationships with other actors. These actors are interdependent, meaning they must rely on and interact with other actors when they carry out their operational and strategic business activities. Awareness of the sustainability efforts of the actors in an organization's business network is becoming increasingly important.

A collaboration among teachers in three Nordic universities to develop a sustainability-related module for master's students started in 2021 as a result of research-related discussions. We found similarities in the content of the courses we were responsible for, so we started to sketch a collaborative course module focusing on a shared interest in business relationships and sustainability. The module was first developed and implemented in the course syllabi (Table 1) during the summer of 2021. The course module, called "Sustainability in Business Networks" or in short the "Sustainability Project," is offered to students enrolled in three MSc courses at the three universities at the beginning of their fourth or fifth year.

Table 1. Courses and ECTS

Management of Business Relationships and Networks	7.5 ECTS	NTNU
Managing Business Networks	7 ECTS / 5 ECTS	Vaasa
Business Marketing and Purchasing	7.5 ECTS	Chalmers

The intended learning outcomes for the three courses include analysis of a firm's business network—that is, how companies can manage their relationships with other companies, understanding marketing, purchasing, and supply chain issues, and relationships' influence on a firm's value creation, innovativeness, internationalization, and productivity. Against this backdrop, the module aims to increase the understanding of the importance of networks and relationships to enhancing sustainability and to enable all students to build professional networks with students from other countries.

TOWARD AN ACTIVE LEARNING APPROACH WITH GROUP-BASED CASES

University student engagement and performance are major concerns, and new pedagogical content is being developed to manage these concerns (McDonald et al., 2020). Passive learning has long been the preferred teaching method, as it directly provides students with the content to be absorbed (Prince & Felder, 2006); moreover, it is convenient and easy, as the instructor-student interface is a one-way interaction (Huggins & Stamatel, 2015). Furthermore, Prince & Felder (2006) state that engineering and science have traditionally been taught deductively, wherein the instructor introduces a topic, illustrates it, and finally tests students' ability to solve a set of related problems in an exam. Students' primary motivation with this type of teaching is that they will need the content later, either during their education or when they start working. However, overusing a passive teaching style may, *ceteris paribus,* reduce students' engagement, understanding of the concepts, internalization of the material, and networking, thus affecting their overall performance (Bonwell & Sutherland, 1996; Prince & Felder, 2006; McDonald et al., 2020). Consequently, course designs, such as active learning approaches (Bonwell & Sutherland, 1996), that facilitate and enhance the extensive required skill sets are needed. In addition, in order to engage students, higher-order learning beyond traditional lectures, fact memorization, fact retrieval, and storing information needs to be facilitated (Van Hoek et al., 2011). Prince & Felder (2006) argue for a more inductive teaching style that is learner-centered in order to counteract deductive teaching. Inductive teaching and learning is an umbrella term for methods that focus on problem-based, project-based, case-based, and discovery learning, among others. These notions compel students to discuss questions, solve problems, and work in groups. Along this line, Scholten & Dubois (2017) discuss an active learning approach to write coauthored books involving supply chain management (SCM) students at the master's level. They found that their course designs "offers unique opportunities to capture and integrate the various skills, competences and perspectives needed for SCM graduates" (Scholten & Dubois 2017, p. 1697). Bonwell & Sutherland (1996) present a conceptual framework for an active learning environment to help instructors in their endeavors to design and frame courses within an active learning environment where student engagement takes center stage; this framework describes a continuum in four areas (see Table 2).

Table 2. Aspects of the Active Learning Continua by Bonwell & Sutherland (1996)

Focus areas	Left end of the continuum	Right end of the continuum
Task Complexity	Simple tasks	Complex tasks
Course Objectives	Acquisition of knowledge	Acquisition of skills/attitudes
Levels of Interaction	Limited interaction	Extensive interaction
Levels of Student Experience	Inexperienced	Experienced

Bonwell & Sutherland (1996) state that an active learning approach is effective and cannot be ignored as teaching becomes ever-more complicated. However, merely adopting such an approach will not make students learn more: instead, what is essential is how the active learning approach is adopted (Prince & Felder, 2006). At the same time, students are a big part of the success of such approaches. There are many reasons why students learn and engage in more advanced learning. Biggs (1991) developed a three-phased model with integrated components: presage, process, and product. Presage concerns student characteristics (e.g., prior knowledge, abilities, willingness to learn) and the environment in which their learning occurs (e.g., curriculum, climate, assessment). Presage affects the Process (and the approach to the task), which centers on how students learn, given their preconceptions and motivations. Finally, the Product of students' learning relates to how much is learned and how well it is learned (Biggs, 1991).

APPROACHING CASE-BASED LEARNING IN A NEW AND INTERACTIVE WAY

Traditional text-based case learning can remain a single-dimensional analysis process if the case narrative covers one issue or situation to solve and/or highlights the knowledge called for by the instructor (McCarthy & McCarthy, 2006). For example, Emblen-Perry (2022, p. 2) argues that "case-based learning as such does not offer the needed flexibility to engage students in the increasingly complex, multi-dimensional, and transdisciplinary concepts of sustainability." Greater use of different problems within a case, a more interactive approach to the case study analysis, and more focus on the discussion phase may be more effective techniques for learning the complex problems related to sustainability (Emblen-Perry, 2022). In addition, a combination of active learning, learning-by-doing, and project-based learning—which requires students to collect, analyze, and synthesize information—may better increase students' cognitive learning of sustainability (Segalàs et al., 2010). In the following section, we describe how we applied different active learning methods to spark master students' interests and advance their understanding of sustainability challenges in business networks.

Description of the case-based sustainability module

The sustainability module focuses on sustainability in business networks and is a group-based, student-centered case assignment. The students are provided with theoretical articles on sustainability and brief backgrounds on three firms in three industries (textile, manufacturing, and food startup) — i.e., one firm per industry. Industry reports and presentation videos related to the three firms are handpicked as study material, and the students are encouraged to also search for additional information about the cases. Finally, some study guidance questions are given to help the students get started with the assignment. The students' task was to describe and analyze the sustainability of the firm's business network and how it collaborates with other firms to enhance sustainability in this network. The module has several components: one written report, one oral presentation, one meeting across university groups, and both oral and written peer reviews on the work-in-progress and the final assignment. In this way, the module aims to incorporate learning from practice, collaborative learning within and across courses and universities, and self-directed learning by handing responsibilities to the groups.

The course module was part of the syllabus for the fall semester of 2021 and the fall semester of 2022. In 2021, the year the collaborative project was launched, only students from Chalmers and Vaasa participated, due to timing issues. At this time, the COVID-19 pandemic was causing all teaching at all three universities to move to online formats. As a result, we used a purely online format in 2021, whereas in 2022, we mostly used the online format but managed some aspects of the course on campus at our respective universities. The pandemic-induced online format might also have led to us setting up and implementing this type of collaborative assignment. From the start of the collaboration design, a teaching team was formed; the teachers knew each other before, as they are part of the same academic community. This teaching team has met regularly (primarily online but sometimes in person) during the years, a shared Teams area has been used to share documents. The associated guest lectures have also been coordinated across universities. Still, the assignment needs to fit into each individual course's syllabus, and these courses vary in their requirements for oral assessments of case reports, meaning that the grading of that element differs. Students had approximately five weeks to complete the course module, which ran simultaneously at the three universities. All students had the same assignment syllabus, which introduced the assignment, suggested readings, and the proposed cases, of which the students selected one to work on.

Number of students and throughput

The number of students from each university is summarized in Figure 1 below. The total throughput has been 264 individual students, divided into 44 groups.

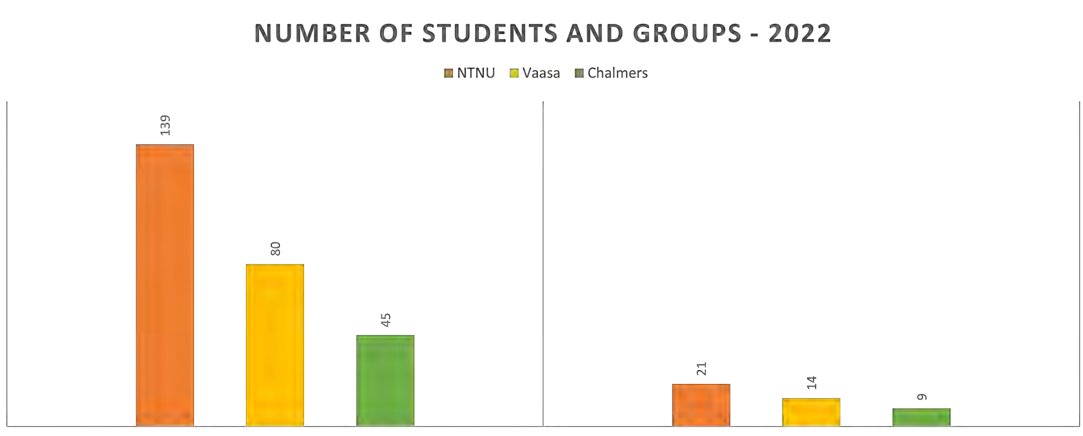

Figure 1. Number of enrolled students and groups at each university in 2022

The module was one part of the three universities' respective courses, and the throughput was very high, considering the group-based nature of the assignment. In addition, most groups completed the assignment satisfactorily (see Table 3).

Table 3. Throughput and distribution of grades

Points / Percentage within each grade category	8–10p	11–13p	14–16p	17–20p
NTNU	15%	18%	52%	15%
Vaasa	-	6%	48%	45%
Chalmers	-	11%	67%	22%

METHOD

We used a qualitative research design to investigate how this case-based module involving collaboration among three Nordic universities could result in an enhanced understanding of sustainability in business network courses. We collected data from students' reflective assignments, students' course evaluation testimonies at the end of the course (including questionnaires), and teacher observations and reflections.

We conducted qualitative comparisons of the students' satisfaction ratings, their experienced workload (self-reported), free text comments from course evaluation forms, feedback received during the module, and teacher reflections on the module itself but also on the collaboration among our respective courses, using qualitative coding and analysis of themes emerging from the data (Miles & Huberman,1994; Maxwell, 2012; Flick, 2014). We also used the Active Learning Continuum by Bonwell & Sutherland (1996) and the three-phase model by Biggs (1991) to analyze how to integrate a sustainability module using active learning and inter-university collaboration.

DISCUSSION OF RESULTS

Student learning and engagement

The results show that the students enjoyed the sustainability module and gained good insights into how firms manage sustainability in their networks. Additionally, students expressed that the approach was new and innovative: many students had previous experience with group-based work, but not in the format provided here, with multiple stages that needed to be completed before the final submission of the report. The feedback indicates that the students obtained much of their understanding through analyzing the firm's sustainability efforts in light of the theory provided in the course, enabling them to see connections between firms and larger systems: for example, "more learning is done through the assignment [in the module] than from the lectures." The students enrolled in the course ranged from moderate-experienced to experienced, and it was clear that the more experienced student groups managed to perform better than those with less experience. The students picked groups themselves, and many were homogeneous in terms of the study program and prior knowledge. However, some suggestions referred to a larger mixing of groups: "Given that the Vaasa students are from a commercial background and NTNU/Chalmers students have a technical background, it could have been interesting to form the groups across universities to gain different aspects and knowledge to the discussions throughout the course work."

Students appreciated the freedom they had and the chance to be involved and contribute to their own assignments. We gave them basic questions to consider and some starting points in the literature, but beyond that, the groups could decide much for themselves. Subsequently, within- and between-groups collaboration worked well, and the groups met several times throughout the module's duration. Even though the group work occurred on campus in each country, it was a positive experience for the students to be able to meet in person in their respective countries (2022) compared to purely online (2021). In this way, we tried to balance the present trade-off between dictating tasks so as to maintain a focus on the objectives and allowing the student groups the autonomy to choose their own approach and angle for the assignment, thereby increasing their motivation (Prince & Felder, 2006).

Students must engage with and take significant responsibility for their learning (Biggs, 1991; Bonwell & Sutherland, 1996); this means they need to know where they need to focus more, where there are gaps in their knowledge, and what information they need to obtain in order to successfully deliver all the assignments in the module. The findings in all three universities show that some student groups were more equipped to deal with the ambiguities and the self-directed learning responsibilities than others. Some groups enjoyed the module, while others did not, and some were more motivated to engage in deep learning than others. This was seen in the peer review and the final report assessment, where it was clear that those who engaged in deep learning showed analytical depth and innovative approaches to the assignment: they not only did what was required but also added their reflections to a larger extent than other groups. The students came from different backgrounds, have different majors and nationalities, and are at different stages in their studies. Collaborative group learning plays a key role in the students' learning process, the slightly homogeneous group formations notwithstanding (Yazici, 2004). Here, peer interaction and constructiveness are key traits, as learning occurs in a social context (Grabinger & Dunlap, 1995).

As such, the groups also met with another group at another university to discuss the assignment. They did not necessarily meet with a group analyzing the same firm, in order to broaden their understanding of the topic; in this way, they shifted focus from comparing how groups with the same company approached the assignment to elevated learning that involved helping each other, which required understanding of the subject matter (Biggs, 1991; McDonald et al., 2022). As such, "we had different companies, which served as a platform for both teams to learn something outside our 'own' company." Since the learning environment is different from encountering real-life problems, students need to be able to transfer their knowledge to new situations (Grabinger & Dunlap, 1995; Bezanilla et al., 2019): for example, "It was great to work on a case of a real company and get to know that well." We found that current and accurate information on a firm's sustainability efforts is vital for students to associate and empathize better, leading to a transition from lower-level to higher-level learning (Van Hoek et al., 2011).

Student satisfaction and workload

Students were satisfied with the module and appreciated the new approach to learning about sustainability, with its various connectors to theory, practice, and responsibility for their own learning: for example, "The chance to collaborate with NTNU was the most exciting part of this module, as it was a whole new experience for all five of us in our group." However, they saw areas for improvement, as reported in the following four quotes:

"We suggest considering giving time to work independently from the other universities as not all the activities have to be managed simultaneously. Leave the meeting, presentation, and

peer review by the time Chalmers and Vaasa start with their assignment; this will help to decrease the workload on NTNU students and improve the time management and the quality of the reports."

"The multi-step nature of the module is one of the things that confused the students."

"The assignment demands much work in a short time."

"Given that the Uni Vaasa students are from a commercial background and NTNU students have a technical background, it could've been interesting to form the groups across universities to gain different aspects and knowledge to the discussions throughout the course work."

Instructors' reflections

Sustainability is becoming a huge part of our teaching environment, with universities rolling out instructions that it should be integrated into all subjects. This is important and challenging, as we need to develop novel approaches to tackling and framing future problems. We tried to achieve this by taking an active learning approach that included collaboration among three universities and many small assignments that served to evaluate the acquired knowledge and provide opportunities for the students to network and learn from peers. From a teacher's perspective, the planning of the module presented a considerable challenge: coordinating learning and scheduling for three courses for the common parts of the module. It was also challenging to frame the module to fit a diverse group of students from various backgrounds. However, following the framework by Bonwell & Sutherland (1996), we designed the module to be positioned toward the right end of the continuum, as the subject requires dealing with relatively complex tasks and theory-heavy notions that must be transferred to practice; as such, the module is about acquiring skills that can be used post-graduation. All in all, the teaching team and the discussion made us concentrate on the sustainability project and learn from each other's courses; in that way, we managed to jointly develop this case-based assignment.

Given the students' Presages, we saw a huge variety in the Processes (Biggs, 1991). This was evident in the Q&A sessions, written peer reviews, presentations, final reports, and self-reported testimonies. It is clear that many students only scratched the surface of their potential learning, as many of the reports only discussed the bare minimum. The achieving approach was also evident, as many students have well-developed study skills at this phase of their studies. Those students with a deep approach saw it as interesting and were intrinsically motivated to learn the subject. To move forward sustainably, we need to activate students' (sleeping) deep approaches to elevate discovery learning (Prince & Felder, 2006) as well as prepare them to think critically and improve their analytical skills (Bezanilla et al., 2019). In addition, those with intrinsic motivation are highly valued in a collaborative setting, as they can engage demotivated students.

CONCLUSIONS

Our conclusions are twofold. The first part relates to our first research question: developing a course module to provide the students with a more holistic and systemic view of sustainability. The second part relates to how to enhance active student learning. In general, we have found that the module has chiefly been beneficial; however, we will develop the content based on the data from the two years it has been taught, wherefore we provide suggestions for each issue on how to develop the course.

Toward providing a holistic view of sustainability

The initiative provides a sought-after addition of sustainability related to managerial issues to traditional engineering education and a more holistic and systems approach to dealing with sustainability. Our findings show that a holistic approach in a case-based sustainability module is warranted and can facilitate and engage student learning and teacher discussions. We thus echo recent suggestions by Malmqvist et al. (2022) as well as McDonald et al. (2022) and Emblen-Perry (2022). Furthermore, we can determine that students are more involved in and learn better through empathizing with the case contexts and associations. This can be achieved through the following practices:

- Having clarity and an undertone of urgency in the case materials, such as information on the sustainability impact of firms and the implications thereof, motivates students to strive and discuss approaches to responding to sustainability issues as 'wicked problems' (Lönngren, 2021) in networks.
- Flexibility in choosing sustainability issues/focus: the students can choose cases they are interested in and empathize with, and thus they will learn better.

A specific focus was placed on how firms, in collaboration, do business, along with the effects of their interactions. Consequently, integrating sustainability into courses like the ones described above is timely, as it provides insight into various aspects of the business environment and gives students professional management skills that the industry has long required (Scholten & Dubois, 2017). This fosters a win-win situation for business, society, and the environment (Kolb et al., 2017).

Towards providing a holistic view of sustainability: Suggestions for future development

One way to give students more freedom is by letting them find and select the case themselves. They may be more interested if they have ownership of the case and if they possibly have prior knowledge of it. This suggestion is also related to our second issue, discussed in the next section. Another tactic could be having a kick-off lecture with a compelling sustainability case given as an example.

Toward enhancing active student learning through case-based teaching

Our findings show that a case-based module based on an active learning approach is warranted in order to enhance active student learning. The timeliness and appropriateness of the module and of the inductive and active learning approach (Kunselman & Johnson, 2004; Druckman & Ebner, 2018) are captured in this testimony: "We believe that the collaborative learning methods will help us develop higher level thinking, oral communication, self-management, and leadership skills to expose and increase our understanding of diverse perspectives." As such, we provide a timely, relevant, and engaging module that allows for higher-order learning (Van Hoek et al., 2011), achieved by:

- Engaging in cross-border collaboration and with students from diverse backgrounds, which enables them to share perspectives that instigate awareness and appreciation around varying viewpoints (given the differences in the country and university cultures).
- Flexibility in choosing cases, wherein the students can choose cases they are interested in and empathize with, therefore learning better.

In addition, active learning emphasizes not only content knowledge but also the development of skills, engagement, attitudes, and values. We also see the pros and cons of student collaboration across universities. Student engagement and learning require a plethora of learning and teaching methods and approaches. Getting students engaged is vital and can be achieved through content-related presentations, peer reviews, formal and informal discussions of work-in-progress assignments, and involving the practical dimension. This can be further achieved by encouraging self-directed learning and handing over more responsibilities to the students, promoting the nature of the instructor as a facilitator of learning instead of an expert.

Toward enhancing active student learning through case-based teaching: Suggestions for future development

1. Combine groups across universities, because this would be new and exciting for students, thereby increasing their eagerness to learn and show their learning to peer groups.
2. Groups could be organized according to the case firm, so that we have groups based on the same firm or set of firms. For this suggestion, we might need more cases so that we do not have too many groups working on the same case. This would also add variety to the reports and presentations. Another alternative would be to have no pre-prepared cases, only general sustainability articles (and a set of lectures); this would allow the students to select a company they are interested in or have prior knowledge of (for instance, as an employee). With this approach, we would guide the students to seek material from annual reports, news articles, etc., thus further adding ownership and the possibility to co-develop.
3. A discussion forum for a set of groups, with the intention that they should meet several times during the course to generate ideas, discuss work-in-progress reports, and evaluate each other's final reports.
4. The student groups could become active parties in the module, in the sense that they would plan, coordinate, and execute the module. This would encourage co-development of the module, focusing on active learning and student ownership and engagement.

In conclusion, we encourage teachers who teach sustainability-related modules to use a combination of innovative active learning methods in order to facilitate students' in-depth understanding of complex sustainability-related challenges. The experiences from our Sustainability Project module presented in this article were chiefly positive and provided the students and teachers with not only positive learning outcomes, but also a welcome change from lectures and traditional written assignments and exams.

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TEACHING COMPETENCY DEVELOPMENT FRAMEWORK FOR SRMIST FACULTY MEMBERS

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ABSTRACT

In this rapidly changing technological scenario, need for a well-qualified professionals with multidisciplinary abilities will be in greater demand. This requires reforms in education promoting more focus on know–how to solve problems with critical thinking, do multidisciplinary projects with creative thinking and innovate in cutting-edge areas of all disciplines. Since the faculty member plays a key role to maximize student learning experiences and attainment of learning outcomes, the professional development of faculty members must be at the core of the basal reforms in the education system. In SRM Institute of Science and Technology (SRMIST), faculty members are encouraged to participate in professional development programmes and outcome-based education workshops. Since the programmes and workshops offered are mostly at an introductory knowledge level, the expected outcomes couldn't be attained as expected especially at the implementation level. Faculty members at all levels may need to re-skill in respond to new initiatives at institution level and directives from government bodies. Effective use of ICT tools in teaching and learning process by the faculty members is of paramount importance in the current scenario. Hence, it is evident that there is a clear need for professional development framework for faculty members to achieve the desired outcomes. This paper describes the design and development of teaching competency development framework for SRMIST faculty members using ADDIE instructional system design model, TPACK (Technology Pedagogy and Content Knowledge) and UNESCO ICT-CFT (Competency framework for teachers) frameworks. This framework covers the professional, techno-pedagogical and organizational competencies every teaching faculty member should possess.

KEYWORDS

Professional development, competency framework, ADDIE model, TPACK, UNESCO ICT-CFT, SOLO taxonomy, constructive alignment, Standards: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

INTRODUCTION

A working group highly proficient in instructional design and educational technology was formed at SRMIST to develop the teaching competency development framework. The group had analysed various instructional design models that many training developers use to maximize learning experiences. After series of discussion and analysis by the group, ADDIE instructional design model was chosen to design and develop the teaching competency development framework for SRMIST faculty member (Peterson, 2003). ADDIE is an acronym for the five-step process: Analysis, Design, Development, Implementation and Evaluation (Tu, Zhang, & Zhang, 2021).

Effective use of ICT tools in teaching and learning process by the faculty members is of paramount importance in the current scenario. This framework includes the Technology Pedagogy Content Knowledge (TPACK) and UNESCO ICT-CFT (Contemporary Framework for Teachers) model based competencies required by the faculty members to use technologies in services such as understanding ICT in education, curriculum and assessment, pedagogy, application of digital skills, organisation and administration, teacher professional learning and develop learning contents for 21st century learners (United Nations Educational, Scientific and Cultural Organizations, 2019).

The structure of this paper is organized as follows: (a) Needs Analysis (b) Design and Implementation of Framework (c) Implementation and Evaluation of Framework (d) Conclusion.

NEEDS ANALYSIS

To design a framework, we performed a needs analysis, as shown in Table 1 through preferences from faculty members on competence development using need identification forms, discussion during performance appraisal meetings, academic planning meeting regarding implementation of new initiatives and policies framed by government and institution level, survey questionnaire on faculty skill gap analysis and course/programme exit survey from students (Dervenis, Fitsilis, & Latrellis, 2022).

Table 1. Framework Analysis Methodology

ADDIE model stage 1	Process
Framework Needs Analysis	New initiatives/policies from government and institution level (National education policy 2020, CDIO)
	Existing faculty development programmes and scope of improvements
	Faculty member needs analysis
	Student needs analysis

Analysis on New Initiatives/Policies from Government and Institution Level

According to the National Education Policy (NEP) 2020, Government of India, higher education institutions should revise and revamp all aspects of the education structure, including its regulation and governance, to create a new system that is aligned with the aspirational goals of 21st century education, including Sustainable Development Goal (SDG) 4.0, while building upon India's traditions and value systems (Ministry of Human Resource Development, 2020).

SRM Institute of Science and Technology (SRMIST) has adapted CDIO initiative in the year 2021 to create a new education system that is aligned with institute's mission, SDG 4.0, fundamental policies of NEP 2020 for higher education and requirements for accreditation bodies. As per SRMIST CDIO implementation plan shown in Figure 1, the faculty members' technical and teaching competence development is identified as the top priority in the academic year 2021-2022 for successful implementation of CDIO approach in all the engineering programmes and also in all other non-engineering programmes from 2023-2024 academic year onwards.

This analysis gave insight to connect the philosophy of CDIO such as designing CDIO curriculum, providing integrated learning experiences, adapting active and experiential learning strategies, and accessing student learning in this framework. This framework also addresses faculty members' professional competencies including strategic skills, leadership skills, interpersonal skills and technical skills; organizational competencies such as performance skills, modelling skills, development skills and delivery skills; techno-pedagogical skills to meet the requirements specified in NEP 2020.

Analysis on Existing Faculty Development Programmes

The newly joined faculty members at SRMIST are given induction regarding learning outcomes - significance & articulation, educational taxonomies for cognitive, psychomotor & affective domain, active learning pedagogies, assessment techniques and the use of Information and Communication Technology (ICT) learning tools and strategies. From the analysis, it's identified that the existing teaching and assessment methods adopted by the faculty members are not well designed to best achieve the intended learning outcomes. To better achieve the intended learning outcomes, knowledge on Constructive Alignment (CA) approach is included in this framework. CA approach bring forth a framework to align the teaching and assessment to attain the outcomes (Biggs, 2014). Since the SOLO (Structure of Observed Learning Outcomes) taxonomy has more advantages over the other educational taxonomies in the evaluation of student learning and also associates well with the CA, it's been included in the framework (Biggs, & Collis, 1982). SOLO taxonomy makes both teacher and students to progress from surface to deeper constructive learning which are mirrored with its levels such as Pre-structural, Uni-structural, Multi-structural, Relational and Extended abstract.

Faculty Member Needs Analysis

The faculty members' teaching competence development preferences are identified through need identification survey. More than 2,000 faculty members of all levels in engineering, medicine and health sciences, science and humanities, management, law and agriculture programs participated in the survey that identified the competencies needed for development, which are part of the framework. Since the faculty members at senior levels may need to re-skill in respond to new initiatives at institution level and directives from the government bodies, they have actively taken part in this survey. The survey analysis shows that the faculty members would like to acquire more knowledge on the following:

(i) End to end accreditation process
(ii) How to motivate and engage students
(iii) Reflective teaching
(iv) Data driven instruction
(v) Effective ways to maximize learning attainment
(vi) Adult learning strategies
(vii) Conducive infrastructure for implementing active learning strategies

(viii) Teaching using digital technologies
(ix) ICT tools based formative assessment
(x) A common platform to share and learn best practices in teaching core subjects
(xi) Effective integration of simulation/design tools in learning management system (LMS) for teaching and learning
(xii) Instructional material design using ICT tools

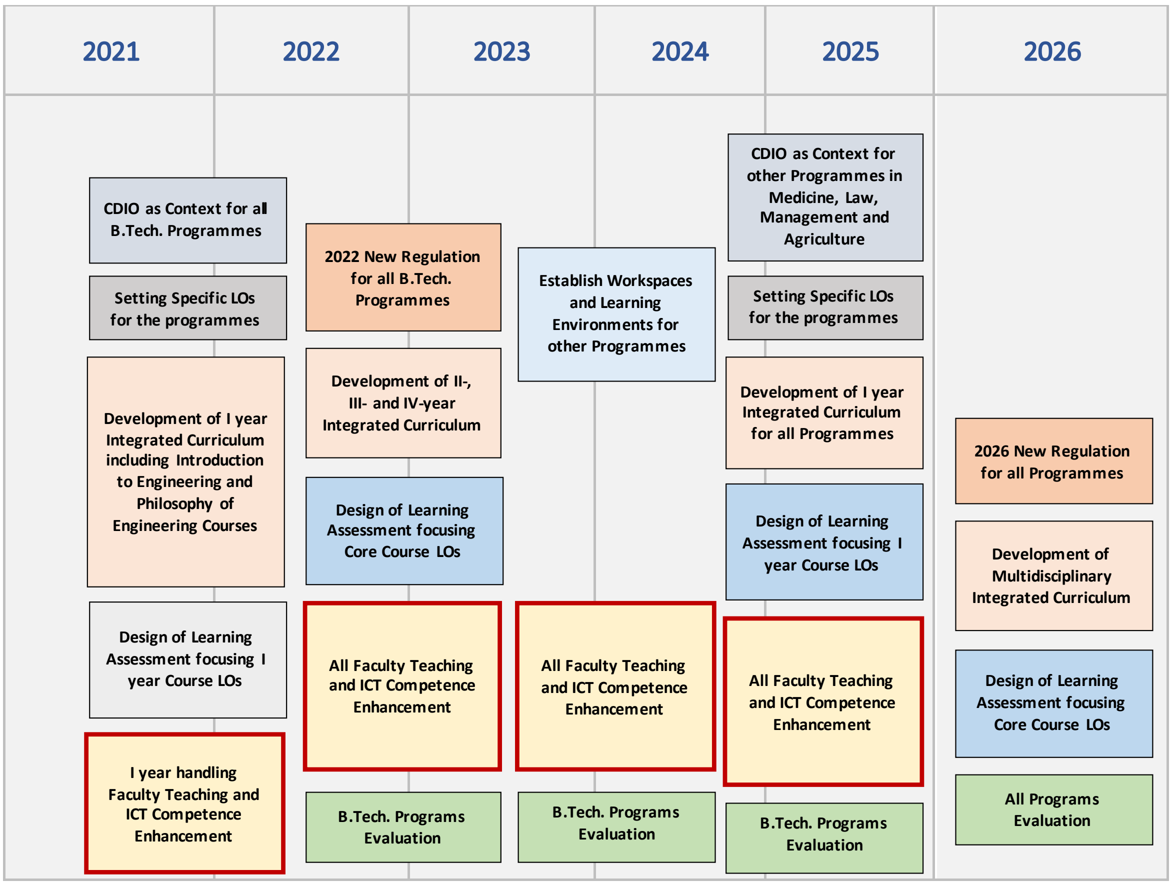

Figure 1. CDIO implementation plan at SRMIST

Student Needs Analysis

The students' expectation on teaching and learning process was analysed through inputs obtained from course and programme exit survey. Students from all disciplines including engineering, medicine and health sciences, science and humanities, management, law and agriculture have taken part in this survey. Through analysis, it's identified that the students in common expect the following requirements in all parts of education system to achieve the learning outcomes:

(i) Multimedia instructional materials
(ii) Creative thinking guidance
(iii) Conducive smart classroom atmosphere
(iv) Multi-disciplinary and flexible curriculum
(v) Teaching and learning with ICT tools

(vi) Blended mode of teaching and learning
(vii) Flipped classrooms
(viii) End to end product design guidance and facility

DESIGN AND DEVELOPMENT OF FRAMEWORK

The faculty competency development framework's main focus is on determining the science of learning and science of instruction in teaching and learning practices. Before beginning the design process, the expectations from the faculty, students, initiatives by the institution and government obtained through needs analysis process are mapped together to check the correlation. The framework is designed considering the constraints and resources determined through the mapping process.

The major design features include:

(i) Three phases of faculty competence development programmes: Knowledge Acquisition, Knowledge Deepening and Knowledge Creation.
(ii) Articulate learning objectives and outcomes for all the phases of competence development programmes
(iii) Create lessons for each learning outcomes and prepare detailed lesson plan.
(iv) Use of ICT tools in the active learning approach and assessments planned in every learning session of the competence development programmes to maximize the learning experiences.
(v) Application of andragogy and heutagogy principles in all the learning sessions, so that faculty members being the self-directed individuals will make the best of learning journey.
(vi) Incorporation of guided learning, individual and collaborative learning and work based learning approach in each phase of the development programme.
(vii) Assessment of learning through written assignment, quizzes and appropriate evidence submission for work based learning.

The level of ICT competence is increased in each phase of the competence development programme for a better and more robust understanding of the subject matter thus balancing the UNESCO ICT-CFT (Contemporary Framework for Teachers) and TPACK (Technology, Pedagogy and Content Knowledge) frameworks (Mishra, & Koehler, 2006). ICT tools used in these programmes include presentation tools, mind mapping and concept mapping tools, virtual classrooms, whiteboards, collaborative and social learning applications, learning and sharing tools, subject related applications and software, eLearning tools developed by SRMIST (Rajeev, & Vairavel, 2021), audio and visual document development tools, learning content management system, learning management system, computer aided assessment and evaluation and learning analytics tools (Hanson, & Fors, 2009).

Development of Learning Phases in the Framework

In knowledge acquisition phase, the faculty members learn about the fundamentals of outcome-based education, CDIO standards, CDIO curriculum design, application of adult learning theories, active learning strategies, ICT tools used for teaching and learning, formative and summative assessment techniques using ICT tools. Integrated approach is adopted for guided learning sessions (integrating both knowledge and practice) and is better handled through appropriate active learning methods. Mentoring is adopted to guide and support the faculty members to complete the tasks to be submitted as per the programme content in portfolio. Senior faculty members who is trained on delivery methodologies and assessment procedures that are covered in this framework are assigned as mentor. Experiential learning is promoted by allowing the faculty members to observe the teaching and learning methods adopted by experienced faculty members. Formative assessments are conducted periodically to ensure the learning outcome is attained.

In knowledge deepening phase, as a part of work-based learning, faculty members are encouraged to apply the learning in phase I of the competence development programme in the courses they teach in classrooms. Faculty member prepare a detailed session plan with suitable active learning approach and formative assessments using ICT tools. Mentor allocated to each faculty member will agree upon the objectives before the class session, observe the teaching method adopted during the session, reflect and discuss on teaching method adopted after the session. This learning by doing practice brings a new experience for the faculty members. As a part of individual and collaborative learning, faculty members are encouraged to reflect on their new experience individually and also discuss about feedbacks from the mentor. The faculty member is allowed to collaborate with other members to understand each of their new experiences on the methods adopted. By adopting this do/review/learn/apply method in the program, faculty members construct their own unique personal meanings or understandings of their experiences and this leads to constructivism.

In knowledge creation phase, using modern ICT tools, faculty members are trained to design, develop and format instructional materials, analyze the effectiveness of active learning approach adopted in classroom through student feedback and generate report, do curriculum analysis through data driven techniques. As per the design plan and features, the framework developed for teaching and ICT competence development is shown in Table 2.

Table 2. Teaching Competency Development Framework

Phases of Competency Development	Approach	Learning Outcomes
Phase I Knowledge Acquisition	Guided Learning, Individual and Collaborative Learning	Understand the philosophy of Outcome Based Education, new initiative/policies by the government and institute level, accreditation process
		Articulate Programme and Course learning Outcomes
		Self-Evaluate a programme with CDIO Standards
		Design a CDIO Curriculum using mind/concept mapping tools
		Review and Understand Adult Learning Theories
		Understand ICT in education
		Understand the application of Organizational Competencies and

		Professional Competencies in the given scenario
		Identify Active Learning Strategies for intended learning outcomes
		Design an Effective Lesson Plan with well aligned pedagogical approach and assessment for the intended outcome (Constructive Alignment Approach with SOLO Taxonomy)
		Select and use appropriate Digital Technologies for teaching and assessment
Phase II Knowledge Deepening	Guided Learning, Work Based Learning, Individual and Collaborative Learning	Practice the lesson planned in the phase I by integrating ICT tools across teaching, learning and assessment process
		Design and practice a sequence of correlated lesson plans with collaborative and social application supported (eLearning 2.0) project/problem-based learning activities.
		Design and practice Blended Learning approach using varied digital tools to promote higher order thinking and problem-solving skills.
		Reflect about the work-based learning with senior colleague to improve professional practice.
Phase III Knowledge Creation	Guided Learning, Work Based Learning, Individual and Collaborative Learning	Design, develop and format instructional design materials using audio and video development tools
		Compute learning outcome attainment using Data-Driven techniques
		Generate report for continuous improvement

IMPLEMENTATION AND EVALUATION OF FRAMEWORK

In SRMIST, a teaching developer group is created with senior faculty members above five years of teaching experience volunteered from each department to act as a mentor. The faculty members enrolled in this competency development programme will be mapped with the available mentors who work in the same department to ensure support and effective learning. The mentors have qualities such as genuine desire to be personally involved, ability to communicate, empower others, professionalism and supportiveness that are required for this competency development programme.

This three phases of teaching competency development programmes are successfully completed in the year 2022. Initially 60 faculty members including all levels were trained with the support of the mentors. At the end of the training, the faculty members are assessed through an ePortfolio of evidence, submitted to a team of internal experts using learning management system. Assessment of learning is evaluated through written assignment, quizzes and appropriate evidence submission for work based learning in their respective ePortfolio. Based on the evaluation of the learning outcomes attainment and collective feedback from the mentors, the delivery methodologies were corrected in appropriate sessions to maximize the learning experiences. The trained faculty members are assigned as a mentor for the next cohort of faculty members to get trained. So far 200 faculty members from all disciplines are trained effectively. The learning experiences shared by the trained faculty members is really encouraging. The summary of the feedback given by the faculty members trained in this competency development programmes is shown in Figure 2. The performance indicators considered for analysis are usage of effective Active Learning Methods (ALM), appropriate Learning Content and Resources (LCR), ICT tools and different Assessment Methods (AM) in the training. The analysis in Figure 2 shows more than 50 percent of the faculty members have given excellent for ALM, LCR and ICT, very good in the range from 11 to 46 percent for all the four indicators. Below 50 percent have given excellent for assessment methods used which is considered for improvement by including more varieties of assessments in the upcoming training.

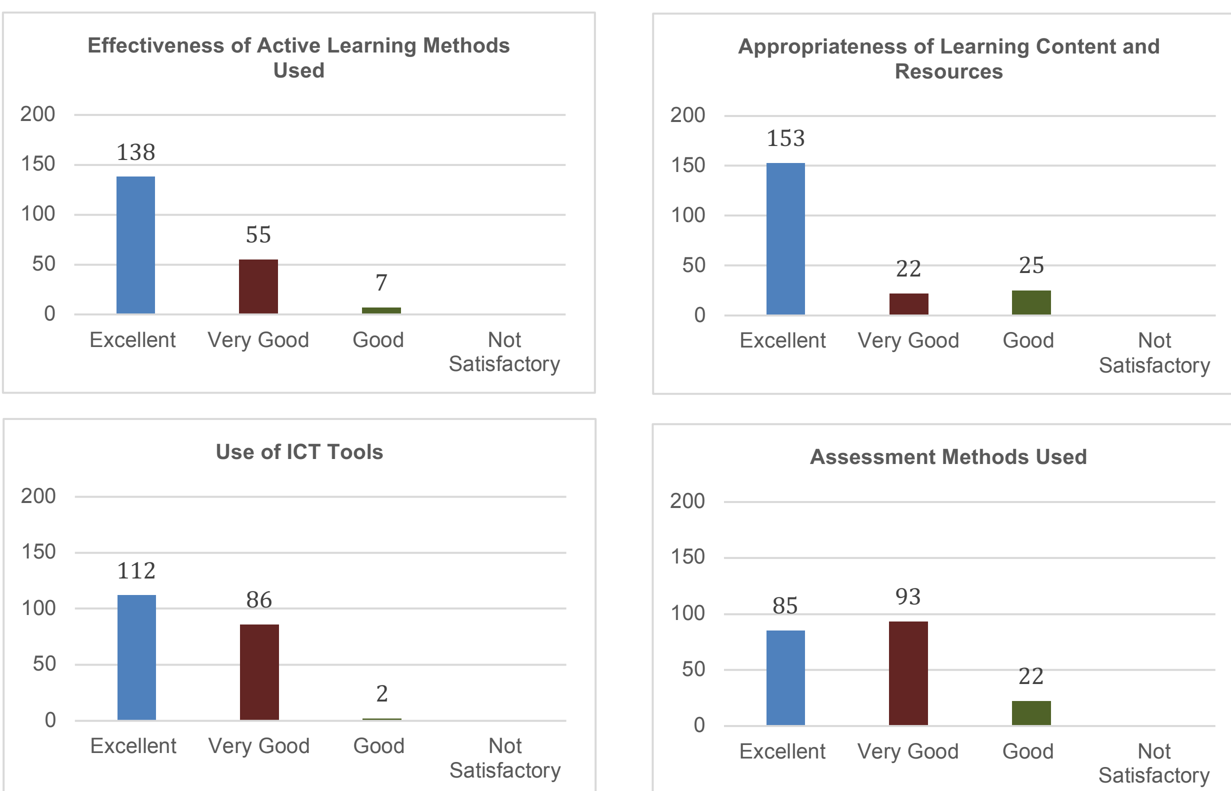

Figure 2. Feedback Analysis

LIMITATIONS AND CHALLENGES

The limitations and challenges encountered during the development of this framework are extensive analysis of the data collected from 40000 plus students and 2000 plus faculty members from different disciplines and mapping all the expectations in the different phases of learning in the framework.

CONCLUSION

In SRMIST, CDIO curricula framework is adapted for all the undergraduate engineering programmes incompliance with the programme learning outcomes defined by the accrediting bodies. This new curriculum revision is effectively implemented from the academic year 2022 – 2023 onwards. Having implemented the curricula revision, now we need to analyze how effectively the integrated course content is delivered by the faculty members and how these competencies developed through this framework maximizes the students learning. The effectiveness of delivery will be analyzed through student feedbacks on teaching-learning methodology adopted by the faculty for the course. The learning effectiveness will be analyzed through evidences of learning, direct and indirect attainment of student outcomes in comparison with the last years student outcomes attainment. The establishment of the teaching competency development framework supports the CDIO curriculum framework and provides guidance for the faculty members throughout their career. As a part of continuous improvement of the programme, suitable skills and areas of improvement will be identified and enhanced in the future. This broad goal is to maximize the students' learning experiences, attainment of learning outcomes, higher order thinking skills and make them industry ready engineers.

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DRONE GAME THAT HIGHLIGHTS ETHICAL AND SUSTAINABILITY IMPLICATIONS OF DESIGN DECISIONS

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ABSTRACT

This paper reports on the development of a brief scenario-based challenge to prompt engineering students' reflection about the broader impacts of their design decisions, and thereby increase their ethical sensitivity and motivation. The game scenario asks players to design a drone for ornithologists to study birds, contextualized as part of a university course. Constrained by their budget, players choose a subset from a variety of actions that can advance their drone design. Each action, for example spending a week prototyping in the lab (200€) or making a one-day field trip with the ornithologists (1000€), allows the players to access specific information and make choices to refine their design. Presenting the task as a mechanical engineering design problem, without reference to ethics or sustainability, gives us a window into how students spontaneously include these aspects in their design decisions. This is important, as previous studies have shown that engineers typically interpret their brief as restricted only to their core engineering disciplinary expertise and do not perceive the ethical implications of their design decisions. The feedback that participants receive after submitting their final prototype highlights potential ethical and environmental issues, with a view to increasing both students' *ethical sensitivity* (recognising that an ethical concern exists) and *ethical motivation* (internal drive towards behaviours coherent with ethical values). This paper reports on the scenario development and first implementation as an online game that constitute the semester project of the second author. We share preliminary participant feedback and our plans for a tangible interface with tabletop robots to observe participants' decision-making processes through haptic functionality and afford opportunities to integrate peer discussions in the activity.

KEYWORDS

Engineering design, ethics, transversal skills, tangibles, Standards: 5, 7, 8.

INTRODUCTION

Foreseeing the potential downstream ethical and environmental impacts of engineering design decisions is difficult for professional engineers even when they possess significant experience with the implementation context. This difficulty is addressed in the CDIO curriculum, for example by Standard 5 which requires two or more design-implement experiences. However, the ability to identify ethical implications for the projects they work on was rated by professional engineers, Masters students and Bachelor students as a relative weaker area of their skills sets (Piccard et al., 2022). It is therefore interesting to create additional, brief and low-resource opportunities in an engineering program that enable students to develop experience with the ethical and sustainability implications of design decisions. This paper reports on the creation of a design challenge "game" to develop students' ethical awareness and sensitivity by confronting them with the ethical and sustainability consequences of their design decisions. This paper is coherent with the motivations for the latest update of the CDIO syllabus (2022) to better reflect the "growing awareness and evidence of the impact of human activities on our planetary system and ecosystems"; this activity prompts students to consider aspects related to section 2.5 Ethics, Equity and Other Responsibilities, particularly the subsections 2.5.1 Ethics, Integrity and Social Responsibility and 2.5.4 Staying Current on the World of Engineering (which includes the social, environmental, and economic impact of new technologies).

"The specific nature of the ethical issues arising from digital technology (e.g. privacy, algorithmic bias or transparency issues)" (Hardebolle et al., 2022) requires that engineers integrate ethical considerations in their technical problem solving throughout the design process. Of course, traditional ethical dilemmas still occur as new technologies are deployed in society. While a recent meta-analysis reports major efforts have been made to improve the integration of ethics in engineering curricula (Watts et al., 2017), several studies point to engineers' ethical sensitivity or ethical agency being insufficient to enable them to productively incorporate ethical concerns in their work. To cite a few examples, Ivan Szekely (2011) found that while IT professionals sought to meet ethical standards, their actions were motivated by seeking to comply with criteria set by their employers rather than responding to their own ethical motivation. Isaac et al.'s (2023) observational study found computer engineering students did not spontaneously include sustainability in their software design decisions, and engaged only peripherally with ethical issues related to either privacy or accessibility. Lönngren's (2021) discursive analysis offers a rich exploration of the perceived separation between ethics and technical, disciplinary thinking.

While it is important to acknowledge that workplace environments contribute to the scope afforded to engineers use ethics and sustainability to inform their choices, the strength of their ethical positions also plays an important role (Hwang and Chen, 2022; Karakoç et al. 2022). Further, Griffin et al. found that engineers tended to minimise the ethical dimensions of their work or to describe the ethical dimensions as beyond their sphere of responsibility (2023). In engineering education, requiring students to employ the perspectives and tools of ethical and value-centered design (Donia and Shaw, 2021) is a promising vector to develop students' capacity to make relevant, contextual connections between their disciplinary design approach and ethical concerns. The expectation that ethics be integrated transversally leads to its classification as a transversal skill in terms of expected graduate attributes set by engineering accreditation bodies (CTi; ABET). We accordingly review our model for teaching transversal skills below.

Teaching Transversal Skills

This project is part of the 3T PLAY initiative, which investigates the development of engineering students' transversal skills using tangibles. As can be verified by a cursory review of the program for any recent engineering education conference, transversal skills are omnipresent in engineering education. Improving graduates' transversal skills requires action at several order of magnitude, from macro-level coordination across the curriculum to the micro-level of the teaching of specific skills through the resources, assignments, and feedback provided to students. 3T Play has developed a three-part framework for this micro-level that describes the elements we have identified essential for transversal skill development (Isaac et al., forthcoming). As shown in Figure 1, the first level is *declarative knowledge* which refers to the actual knowledge and concepts that underpin a skill. Taking the example of the transversal skill of ethics, relevant *declarative knowledge* includes sources of bias in machine learning or the role of inequality in climate change. The next level, *procedural skills*, relates to the integration of this knowledge in thinking and behaviour. Continuing the example above on ethics, *procedural skills* involve generating diverse user stories, employing strategies for equitable teamwork, and designing to promote ecological choices. The final level, *metacognitive and meta-emotional reflection*, refers to the self-monitoring of the efficacy and appropriateness of the *procedural skills* being implemented. This skill involves, for example, the ability to assess the effectiveness of the decision-making or design approach being used in the current moment. Is it suitable for current phase or objectives? If it is working better than expected, why is this and why didn't it work well last time? This third level is related both to developing students' capacity to identify when a different approach is needed and to select appropriate strategies in the present moment. This final level is fundamental to students being able to transfer their experiences from the current learning situation to their next project, and hence relevant to their lifelong learning (Bierwolf, 2017).

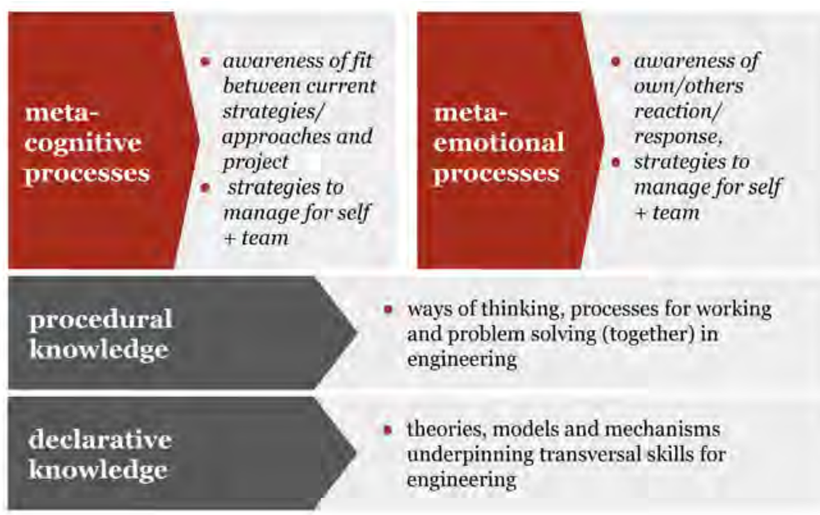

Figure 1. 3T PLAY's 3-level approach to teaching transversal skills

The development of robust transversal skills requires all three of these levels to be addressed over the course of the interventions around the development of a particular skill. Our framework has allowed us to clarify the types of activities and feedback students need to develop a well-rounded skill.

While senior engineering students typically integrate more reflective practices into their design thinking than younger students (Adams et al., 2003), many students requite explicit support to develop their meta-cognitive skills with respect to their design decision (Steele, 2018). It is these meta-cognitive skills that the drone challenge presented in this paper addresses. While it neither teaches about specific ethical or sustainability concepts, nor proposes procedural skills for students to incorporate ethics into their thinking, the scenario seeks to develop students' sensitivity and motivation for identifying ethical and sustainability implications of design choices.

Creating an Ethical Game

Meta analyses have shown that educational games can develop cognitive, affective and motivational skills (Karakoç et al. 2022; Manzano-León et al., 2021). For example, Wang et al. (2021) report that an augmented reality game promoting general environmental actions, such as recycling, resulted in « knowledge absorption » and improved participants' attitudes towards sustainable behaviours. Specific recommendations with regard to ethics education games include "ethical choices and decision-making, which have an effect on the game play" and integrating reflective activities (Schrier, 2015). Mendler de Suarez et al.'s report (2012, p.9) provides a robust argument in favour of games' potential to act as « systems that help us inhabit through gameplay the complexity of decisions about future risks ». In particular, they identify games' (1) power to compress time and therefore allow players to experience how their decisions shape the outcomes or even more long-range future and (2) capacity to "capture relationships between system elements in a way that gives agency » to the player (ibid.). Our understanding of the characteristics that make serious games effective is still being refined, particularly with respect to the meta-cognitive level we seek to access in our game. For example, Tanner and colleagues' (2022) found that their business game did serve to develop university students' moral sensitivity however, in constrast to previous work, versions with pro-social cues or reflection prompts were less effective. As discussed above, we are interested in getting students to integrate ethical thinking in their disciplinary engineering thinking. Accordingly, we are interested in Cécile Hardebolle and colleagues' (2022) development of an interactive scenario for engineering students where players make decisions regarding the design of machine learning algorithms and are confronted with the ethical implications.

With a view to engaging the large number of mechanical engineering students in our institution, informal surveying helped us decide to create a game that challenges players with design decisions related to building a drone. Drones are exciting devices with features and components of varying complexity, allowing for trade-offs during the design process (The Corona Wire, n.d.). Drones are also used for many different purposes (bird monitoring, pipe inspection, delivering supplies to remote areas, etc.) which allows for the development of several scenario within the game, thereby creating opportunities for students to transfer their skills to another context. While the technical verisimilitude is important to us, varying complexity of components also provided scope to make the scenario accessible to people without a specific engineering background. Scope for ethical implications can be found in the potential for drone noise to scare birds; an extreme example occurred when a drone crash caused thousands of elegant terns to abandon their eggs (Washington Post, 2021). Another potential ethical issue is how bias in user testing can exclude categories of potential users, arising from scaling equipment for a healthy, male university-aged person who is likely not representative of the diversity of users in the field.

GAME DEVELOPMENT

As outlined above, the learning outcome for the drone challenge is to get students to reflect on the ethical and sustainability implications of their disciplinary design choices. A drone design challenge was chosen for its attractiveness for bachelors students and scope to integrate ethical issues in parallel to technical ones.

Game Play

The scenario presents as a technical challenge of designing a drone for ornithological field study. Contextualized as a course project, players are provided with a basic drone and given 11 weeks, a small monetary budget, and access to various experts to refine their drone's specifications before submitting their final design. Players choose from a set of actions, such as *speak to the director of the reservoir* or *test in the backyard*; each action is associated with a certain investment of time and / or money. As shown in Figure 2, the actions are presented as tiles on the screen and the player make a choice by dragging a tile to the "enter" box. Once the choice is entered, the player receives specific information in the left hand text box followed by decision proposals (subchoices) to modify certain drone parameters.

For example, players have the option to increase the wingspan of the drone as the result of various actions. The director of the reservoir recommends avoiding medium wingspans to reduce the chance that birds perceive the drone as a predator and testing the backyard identifies stability issues for small wingspans. Players accept or refuse these modifications to their drone parameters (any associated cost is deducted from their budget). Any changes result in the drone specifications displayed in the right hand dashboard being updated.

When the player is satisfied with their design, or have exhausted their monetary or time budget, they submit their final drone design. The scenario concludes with feedback from the several research ornithologists who employed the drone in their work observing birds in Scotland. This feedback is calibrated to the final drone specifications of wingspan, weight, color, etc. and is generated by combining pre-defined sentences based on the features of the drone. The comments are designed to highlight potential ethical and sustainability issues arising from each drone design, and prompt players to reflect on both the intentional and inadvertent effects of the decisions they made in during their design process. In all cases, tensions between design choices, such as between the advantageous increase in autonomy of a larger battery and the accompanying disadvantageous exclusion of smaller researchers unable to carry a heavier drone long distances, are highlighted to increase students awareness of the complexity of real life applications.

Figure 2. Game play interface

Technical Development of the Activity Interface

Unity is one of the most widely used game engines due to its portability across multiple platforms and support of the game creation process. Additionally, the tabletop educational robot Cellulo, specifically developed to “make tangible what is intangible” (Özgür et al., 2017), provides a package for integration in Unity applications. Keeping in mind our goal of incorporating tangibility in this game at the next stage of development, we thus decided to build our game in Unity. Specifically, the current drone design challenge relies on the Unity game engine and was deployed on WebGL, which allows players to play the game via their browsers, with no local download or installation needed.

The current game prototype presents players with 6 actions that give rise to 13 decision points (1-3 decision points per action) which determine 10 characteristics (i.e. weight, user manual, battery life). One decision can influence several characteristics, for example choosing a larger battery extends flying time but also increases weight. Figure 3 presents a simplified interaction chart with 4 actions and 3 characteristics.

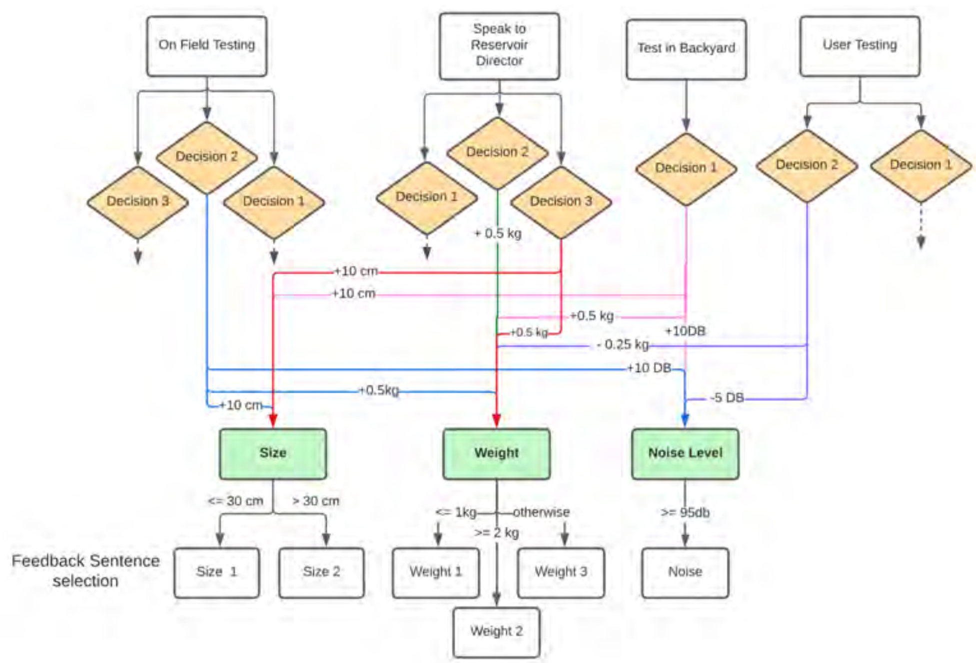

Figure 3. Flow chart showing the relationship between actions, decisions and feedback

Preliminary Testing and User Feedback

In addition to informal feedback on the early iterations of the game, 13 players answered an online questionnaire about their experience in the game. This was a very diverse group of people corresponding to engineering students, educational researchers and mechanical engineers. Players reported spending, on average, 9 minutes playing. As shown in Figure 4, players were engaged by the scenario (item A) and enjoyed the game (item D) despite the topic not being of interest to a significant number of players (item F). That the outcomes of the players choices were not obvious to many players (item G) suggests that the scenario is successful in generating surprise, a useful epistemic emotion for prompting reflection. While we have not assessed this core objective of the activity, it is promising to note that half of players reported that the game will change how they think about design decisions (item I).

Our analysis of the free text responses to the question "What did you learn from playing the game ?" suggests that about half of players experienced surprise or reflected on their design choices but half of players perceived drone knowledge as their major take away. Missing technical drone knowledge was not identified as an issue by anyone in the free text comments, confirming that we were successful in designing a scenario accessible to people without a specific background. While we do want to maintain the engineering context and interplay between ethical and technical considerations, these results suggest that the ethical angle needs to be reinforced.

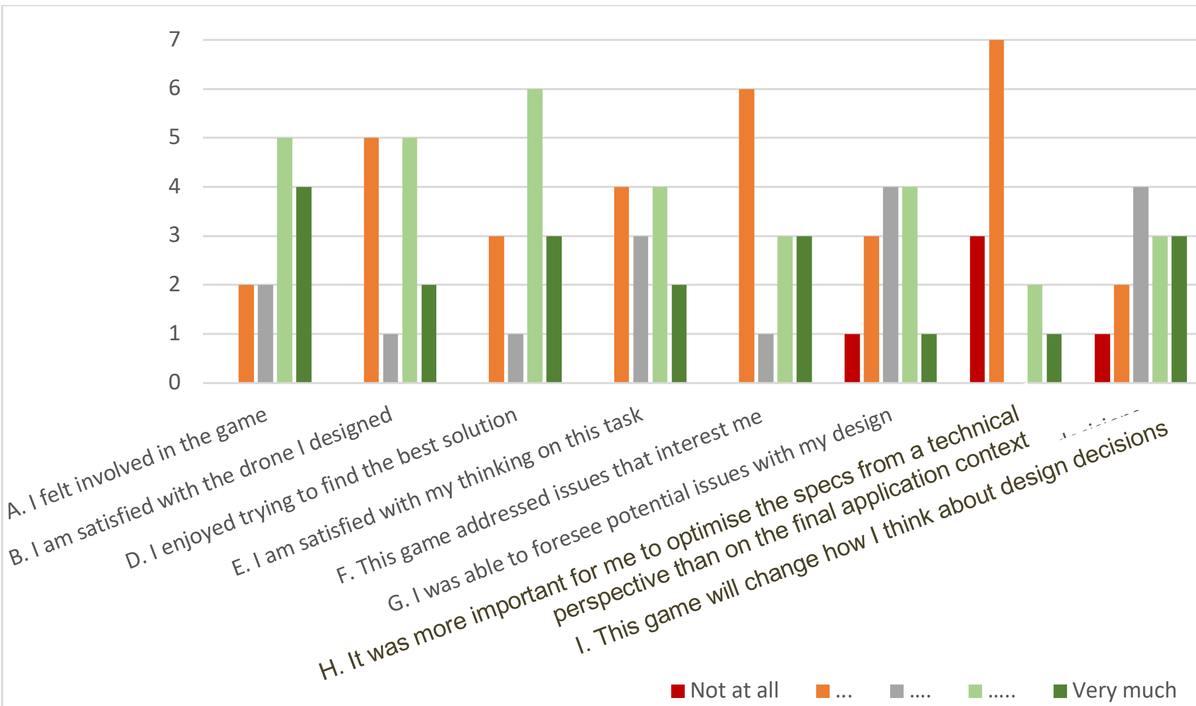

Figure 4. Preliminary feedback from players

Note: Only extremes of the response scale had labels in the expectation that respondents would assign intermediate values to the 3 middle options.

Stimulating Ethical Reflection

While all of the choices presented to players focus on fairly technical aspects, the ethical and sustainability implications of the choices are the central elements in the final feedback. Our goal with creating the scenario in this way was to increase students' ethical sensitivity and motivation, that is their capacity to identify relevant ethical considerations in parallel to their disciplinary or technical reasoning and their commitment to actually doing so. The tensions between favourable and less desirable outcomes for each design choice are highlighted to confront potential epistemically naïve ideas about the existence of a single "correct" design (Isaac, 2021). Thus, the game does not provide a final determination of the success of the drone (i.e. win or lose) but challenges players to experience the ambiguity of having produced a design with both strong and weak points.

The goal here is to prompt some metacognitive and meta-emotional reflection about how students went about their thinking and how they would like to approach design tasks in the future. To continue the example above about wingspan, it appears that a large wingspan is suitable for both birds' perception and drone stability. Figure 3 presents a sample of the interrelations between actions, decision points and the outcomes. However, only field-testing will allow users to potentially identify the implementation issue arising when researchers must carry the drone, camera and other gear on a challenging 3h hike to the remote research site. As shown in Figure 3, when the final drone specifications have a weight $\geq 2\ \mathrm{kg}$ then the final feedback from the fictional ornithologists raises the issue of accessibility by stating that only the tall, athletic young man in the team uses the drone because the difficulty of bringing to the field site.

Characteristics of the Activity

We are uncertain what to call this activity; it is not a game in the sense it is not possible to win nor does it contain gamified elements beyond the creation of an immersive scenario. The term game however is useful for getting students to engage and start playing. Maybe our game is actually an interactive narrative. The decision not to set up a winning condition is intentional: we sought to challenge students' epistemic sophistication by requiring them to rely on their own judgement and not to fulfil expectations of dichotomous right or wrong outcomes (Isaac, 2021). Accordingly, the end of game feedback includes both positive and negative aspects for each design. Players are not told if their design was successful but are instead required to judge for themselves. Feedback from our initial testers indicated that this caused some discomfort. We hypothesize that communicating that this is an intentional outcome will improve the impact of this part of the experience. Fun or enjoyment is another fundamental game characteristic. Our testers found the scenario moderately engaging and were positive about both the learning experience and perceived utility the game. Characteristics of games that are useful include the creation of low stakes environment with rapid feedback. While students are certainly aware that there are no consequences for making poor design choices in this scenario, our goal is that the immersive scenario is sufficient to engage students cognitively and emotionally such that they are surprised or challenged by the feedback they receive at the end of the game. While this scenario replicates a semester long course, the feedback about the drone design and the ethical implications of design choices in the game are available to students quickly and with significantly less investment. The creation of this short scenario is intended to provide students with additional opportunities to make design choices and to receive feedback in a short loop. Our goal is that students would then transfer the experience to their next design experiences.

FUTURE WORK

In the context of developing students' transversal skills and particularly their ethical sensitivity and motivation, we are interested in supporting and challenging students to resolve the complex issues around ethics in their disciplinary contexts. In spring 2023, we look forward to conducting empirical studies to assess participants' reaction to the activity and what they may have learned. On the technical side, students working on this project in the coming semester will integrate Cellulo robots to enable us to leverage their haptic functionality to collect data on participants' decision-making processes and afford opportunities to integrate peer discussions in the activity. In this way, we hope to better understand what elements of the scenario are most relevant for triggering relevant meta-cognitive and meta-emotional reflection. Another interest is the development of teaching resources to equip students with strategies to employ during their design process that can assist in mitigating different types of ethics or sustainability issues.

CONCLUSION

This paper reports the development of a drone design challenge that allows students to experience (or perhaps foresee) ethical and sustainability issues arising from design decisions. Teaching about drones was not the core objective of this project but chosen as an attractive context for mechanical engineers to engage with ethics and technological issues. The goal of this game is to surprise the players with unexpected ethical implications of their design decisions by receiving "from the field" feedback on their final drone designs. Although the testing group was small and included non-students, the scenario seems to show some positive results on the game's impact on how people will think about design decisions. Initial user feedback suggests the balance between technical (drone) and ethical considerations is not optimal to meet our goal for developing students' ethical sensitivity and motivation around ethical implications of their design choices.

In order to fulfil the goal of training our graduates « not only as first-class scientists, but also as engaged and active members of society and leaders of tomorrow » (EPFL, n.d.), we need to ensure that they consider the environmental, ethical and social implication of their designs. The increasing importance of the ethical and sustainability implications of design decisions is reflected in the CDIO syllabus update; this short design challenge offers an accessible way to increase students' opportunities to engage with this important aspects. Further, playful approaches are a promising vector for learning due to their capacity to "help us make sense of complex systems by placing us into the system where we can enliven its dynamics and inhabit its complexity as an active participant" (Mendler de Suarez 2012; p. 10). We intend to refine the scenario and then assess the efficacy of the activity in terms of prompting students to reflect on societal and environmental impacts within the context of their disciplinary problem solving.
CDIO standards 5, 7, 8 are relevant to this project. This activity proposes an active, experiential learning experience (standard 8: active learning) that serves as a useful introduction for the skills targeted in design-implement experiences (standard 5: design-implement experiences) by prompting students to reflect on the interplay between disciplinary problem solving and ethical concerns in their design approach (standard 7: integrated learning experiences).

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BIOGRAPHICAL INFORMATION

Siara Isaac is the project manager and a researcher in the 3T PLAY project at the École polytechnique fédérale de Lausanne (EPFL). Her work focuses on how students develop transversal skills in science and engineering contexts, including her 2022 book with Roland Tormey entitled Facilitating Experiential Learning in Higher Education - Teaching and Supervising in Labs, Fieldwork, Studios, and Projects (Routledge). Siara holds an M.Sc. degree in chemistry and Ph.D. degree in educational research. She has a particular interest in the development of students' epistemic proficiency around managing ambiguity and exercising judgement.

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STUDENT PERSPECTIVES ON ONLINE HYBRID LEARNING IN AN UNDERGRADUATE ROBOTICS COURSE

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ABSTRACT

Many institutions in higher education worldwide are transforming classes into online courses, or into hybrid courses with students participating both physically in the classroom and digitally through video conferencing software. The latter is a growing trend for multi-campus institutions offering the same courses to multiple campuses. Hybrid courses with synchronous learning activities requires a careful balance when designing student-active learning methods between focusing on the students physically present in the classroom, and the students participating online. In this paper, a set of online hybrid student-active learning activities were implemented for a third year robotics course, and we present student perspectives on online hybrid learning collected from surveying students on what learning tools were perceived as useful for their learning. The results show that students generally appreciate how digital tools can activate students in online hybrid learning, and are especially positive to short lecturing videos, online interactive quizzes, and anonymous digital whiteboards for questions and comments. However, results also show that students do not rate online hybrid learning as equally good when compared to face-to-face lectures, and are ambivalent on whether they achieve the learning outcomes equally well through an online hybrid course design. We believe that the results presented in this paper can be of help to teachers designing student-active learning activities for online hybrid courses in general, and highlight some of the learning tools that students give good ratings as helpful for engaging a more student-active learning approach to hybrid engineering courses.

KEYWORDS

Online hybrid learning, Student-active learning, Digital learning tools, Standards: 7, 8, 10, 11

INTRODUCTION

The recent pandemic forced many institutions in higher education worldwide to transform traditional courses from physical face-to-face (F2F) courses into online courses. Also, in multi-campus universities offering the same courses to multiple campuses, there is a growing trend to create online hybrid courses (OHCs) where groups of students participate simultaneously in lectures either through physical F2F presence in the classroom, or through online participation using video conferencing software (Keengwe & Kidd, 2010). These OHCs require a careful balance when designing student-active learning methods between focusing on the students physically present in the classroom, and the students participating online.

Kyrkjebø (2020) proposed a guide to student-active online learning in engineering courses that highlighted the need to align the digital learning tools with the learning objectives, learning activities, and the evaluation methods used in the course. The author proposed a course design for an OHC in robotics, and gave recommendations for how to use different digital learning tools to enable student-active learning for students attending lectures either physically or online. The student-active online learning design was first applied to students in the year 2020 as an online course due to restrictions on students presence on campus due to the COVID-19 pandemic. Gradually, through the pandemic, students have been allowed back on campus, and the course design was applied to students as an OHC in 2021 and 2022. In this paper, we follow up on the proposed design of Kyrkjebø (2020) to show how some of the student perspectives on online and hybrid student-active learning have changed through the pandemic based on survey data collected from students in the years 2020, 2021 and 2022. We also analyse how some of the perspectives seem to indicate a more general opinion on digital tools for student-active learning.

In this paper, we use the term online hybrid learning (OHL) to describe learning methods with a mix of physical F2F learning activities and online (digital) learning activities. This is sometimes also referred to as blended learning. Learning activities can be a mix of synchronous learning activities (SLAs) and asynchronous learning activities (ALAs) (Goodyear, 2002). SLAs require that all students participate in the learning activities *at the same time*, and can also be hybrid SLAs – where some students participate F2F and physically in the same room as the lecturer, and some students participate online in the same lecture. Typical SLAs are real-time lecturing, supervision, discussions, lab exercises in groups, etc. On the other hand, ALAs allows students to take part in the learning activities at different times, and can also be a hybrid mix of using digital tools such as online lecturing videos, online quizzes, online simulations etc., and learning activities that requires a physical presence e.g. as self-supervised individual lab work.

The transformation from traditional lectures to online classes have for many universities been driven by the desire to become more competitive, but also to adapt higher education to a more diverse group of students (Keengwe & Kidd, 2010). Online learning have in some studies been reported to be preferred by students (Hannay & Newvine, 2006), and have also been regarded as more effective for large students groups. Recent political processes to create larger and more robust learning universities have also led to an increase in multi-campus universities where study programs and courses are delivered across campuses. While both pure online and hybrid courses, with a mix of physical and online activities, offer new opportunities to develop new methods in digital pedagogy (Hannay & Newvine, 2006), great care must be taken to ensure that online and hybrid learning does not allow students to become only passive participants in teacher-centred activities. Freeman et al. (2014) found that student-active learning, with more engagement from students in the learning process, is beneficial for learning, and can lead to lower fail-rates and higher examination scores. Wieman (2014) also supports this, and makes the claim that ”active learning methods achieve better educational outcomes”.

OHL can often encourage less motivated students to stay focused on the course, and to feel a greater sense of community, than in pure online courses (Olapiriyakul & Scher, 2006). Hannay and Newvine (2006) also found that some groups of students preferred online presence over physical presence in hybrid SLAs to better be able to balance learning with other commitments. Still, it is an open question whether the majority of students, when given the opportunity to participate either online or physically in SLAs, prefer physical or online participation.

Student perspectives on OHL have been studied in different works – both as perspectives from before the COVID-19 pandemic, and more recently during and towards the end of the pandemic. In Park (2011), students in a lab-based course on Construction management were exposed to 50/50 online and F2F activities. Students evaluated the hybrid approach as better than the traditional physical F2F approach. Students reported that OHL made students more self-responsible for their learning, and gave more flexibility of learning to suit individual students' preferences for learning style and needs. However, weaknesses in OHL was also reported as reduced contact opportunities with instructors, increased responsibility on students, and reduced class-interactions with their peers. Bruff, Fisher, McEwen, and Smith (2013) investigated how massive open online courses (MOOCs) could enhance traditional learning by a combination of online and F2F learning activities. Students regarded some elements positively, such as flexibility, customisation, accessibility and self-paced learning. Lack of alignment between online resources, and too little adaptation of the digital resources to take more advantage of the in-class components, were rated as negative aspects. Bruff et al. (2013) thus advocates for more complex forms of hybrid learning where the online course material is more customised for OHL. Nortvig, Petersen, and Balle (2018) presented a literature review of factors influencing e-learning and blended learning with respect to learning outcome, student satisfaction and engagement, and found that interaction with other students and instructors was the most important factor for learning. Interestingly, the review in Nortvig et al. (2018) found that no inherent features of either online, hybrid/blended or F2F learning activities produced either better or poorer learning outcomes for students, but that the learning outcome is instead very dependent on individual factors for each student.

Nikolopoulou (2022) investigated university students' opinions and preferences regarding F2F, online and hybrid modes of education shortly after the return to campus after the COVID-19 pandemic. The author found that students had positive perceptions of hybrid learning linked to the combination of the positive aspects of online learning (time and space flexibility) with the positive aspects of physical F2F learning (social interaction, ease of students' active participation). Hybrid learning was also regarded positive with regards to adaptability for working students, self-management of learning, and greater equality in education. Negative aspects of hybrid learning were often linked to difficulties in class organisation, a requirement for better teacher preparations, and a lack of familiarity with technology. Students in Nikolopoulou (2022) highlighted a future preference for both F2F and hybrid learning, where F2F learning was preferred in practical/lab activities, but online learning was preferred for more theoretical activities. The authors also report that student preparedness to adopt to OHL has increased during the pandemic. A limitation as stated by the author for the results presented in Nikolopoulou (2022) is that no quantitative data was collected, and that the analysis was purely descriptive.

In this paper, we investigate student perspectives and satisfaction with OHL in engineering for a course in robotics through quantitative and qualitative data collected through student surveys in the years 2020, 2021 and 2022. The paper presents and discusses results on overall satisfaction with OHL, overall satisfaction with digital tools used, and satisfaction with the use of short lecturing videos as ALAs, and with anonymous digital whiteboards and quizzes for hybrid SLAs. Student satisfactions when comparing OHL with F2F learning, and their evaluation of how well they could achieve the learning objectives of the course, are also presented. Lastly, student perspectives in the form of comments to different aspects of OHL are summarised and discussed, and some conclusions and recommendations for OHL are presented.

IMPLEMENTATION

Learning activities were implemented based on the recommendations of Kyrkjebø (2020) in a 10 ECTS course in robotics at the Western Norway University of Applied Sciences in Norway from 2020-2022. The course ran in parallel on two (2020) or three (2021, 2022) campuses, In this section, we provide a description of the learning activities and methods used in the course, and emphasise the hybrid approaches taken to learning for both SLAs and ALAs.

Synchronous learning activities

Lectures were scheduled two days a week for 2-4 hours a day with a maximum of 6 lecturing hours in total per week. Lectures alternated as physical F2F lectures and online hybrid lectures between campuses, where the lecturer was physically present at one campus teaching students F2F in a classroom, while also simultaneously making the lecture available online to students at other campuses, as shown in Figure 1. Online students could either participate together from physical classrooms at their campus, or as individuals from anywhere.

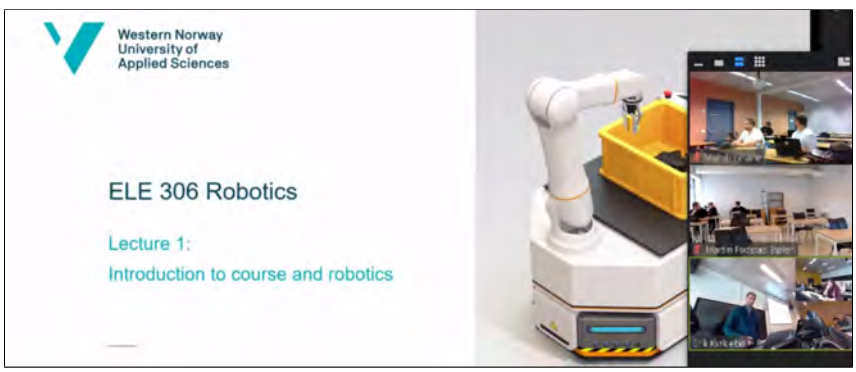

Figure 1. OHL with students participating in the same lecture from 3 different campuses (also as individuals online), and with video from all campuses.

Exceptions to the practice with the lecturer only being physically present at one campus was the first introductory lecture – where there was one lecturer present at each campus, and were each took turn presenting and lecturing from each campus within the same lecture. A limited number of lectures were also conducted as pure online lectures when circumstances did not allow the lecturer to be physically present at the scheduled campus (sickness, transport issues, etc.). A schedule for which campus would have a lecturer present physically, as well as all other relevant course information, was made available and kept up to date for students in a Learning Management System (LMS). In this particular course, Canvas was used as the LMS.

The scheduled lecture slots were used for all SLAs, and included traditional lectures, presentations, discussions, running through examples, quizzes, or project support sessions. In lectures, teachers used digital tools such as powerpoint-presentations or pdfs to go through parts of the curriculum. In discussions, teachers could ask students to reflect on today's curriculum individually before discussing in plenary, or to solve exercises that were followed by a discussion, and then the teacher showed the best way to solve the problem using a digital whiteboard. Quizzes using the software Mentimeter was used both to informally test students' learning achievements at the end of lectures, but also as a tool to explain theoretical concepts and their application to real-world scenarios. A project counted for 25% of the grade in the course, and in addition to project lectures, online project support sessions were set up in some of the scheduled lecture slots where each project group could book meetings with the lecturers. The video conferencing software Zoom was used for all SLAs, and students could interact with the lecturer either through video and audio, through written messages in Zoom, or through the anonymous digital whiteboard flinga.fi (Flinga) for anonymous questions and feedback. Lecturers made a point of ensuring both good video and audio feeds for online students in the hybrid lectures. In parts of the course, the polling feature of Zoom was used to ask students about their expectations to the course, their preparations for today's topic (read material, watched short lecturing videos, or if they had tried implementing examples in simulations).

Asynchronous learning activities

The written learning material (Corke, 2017) was available to students either as a physical textbook, or as a digital book in pdf format. Students were encouraged to read chapters before the lectures. All of the topics covered in the book were also available as short lecturing videos (SLVs) to students – either made by the author of the textbook, or made by the lecturer teaching that particular topic when not available from the author of the textbook. Videos were made available to students either through the LMS, or on the homepage of the author of the textbook. Students were also encouraged to watch the SLVs before each lecture, or to choose either to read the material or to watch the videos. Most lectures thus did not go through all details of the topic, but instead focused on a summary repetition before more student-active learning activities such as quizzes, discussions or examples were started. Student were encouraged to use the LMS for asynchronous discussions under predefined topics. By request, a Discord-server with predefined channels (students were already familiar with and used this platform for other activities) were also set up to provide support with projects, simulations and implementations – mainly focused on solving problems involving code or software. Students also used the direct messaging (DM) feature of the LMS to contact lecturers outside of the scheduled SLAs.

RESULTS

Data was collected from students participating in the robotics course ELE306 Robotics at the Western Norway University of Applied Sciences in the fall of years 2020, 2021, and 2022. The curriculum for the course was the same for all three years, but the order of topics and lectures could vary slightly between years. Data on student satisfaction with online learning was collected through an anonymous survey using SurveyXact after the lectures and exams were finished. Students generally had one month to reply to the survey, and was reminded of the poll twice during this month. In this survey, students were presented with several claims for different aspects of digital learning, and asked to rate them on a five-point Likert scale from *strongly agree*, *agree*, *neither agree/disagree*, *disagree* to *strongly disagree*. The anonymous survey was sent only to registered students for the course, and 20 out 48 responded (41.7%) in 2020, 23 out of 81 (28.4%) in 2021, and 33 out of 79 (41.8%) in 2022).

Data on expectations to the course were collected through the anonymous polling feature in Zoom within the first week of the course, and were only collected from students participating in the synchronous hybrid lecture when it was given – where also students physically present in the classroom were encouraged to log on, and answer the poll online.

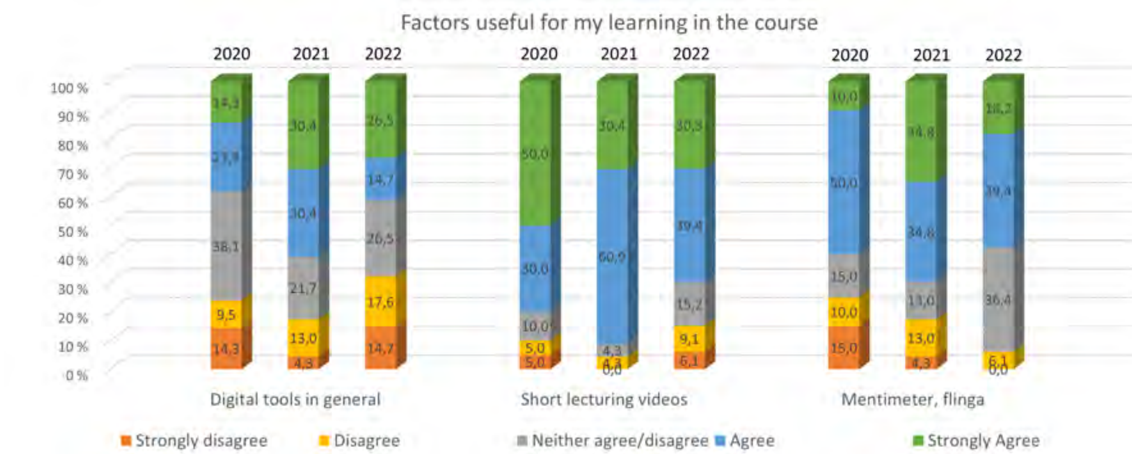

Figure 2. Overall satisfaction with use of digital tools in general (left), satisfaction with the use of SLVs (middle), and satisfaction with the use of Mentimeter and Flinga (right). Data shown for years 2020, 2021 and 2022 in each category. Respondents: 20 (2020), 23 (2021), 33 (2022).

Satisfaction with use of digital tools

Students were asked to rate their overall satisfaction with the use of digital tools in learning. Digital tools included both synchronous and asynchronous tools. Synchronous tools used were the video conferencing system (Zoom), digital whiteboards for writing, sketching and running through examples, standard presentation software (Microsoft Power Point or Adobe Acrobat PDFs), interactive presentation software (Mentimeter), anonymous whiteboards for student questions (Flinga), or polling features in the video conferencing system (Zoom). Asynchronous tools used were the LMS (Canvas), asynchronous SLVs made for the course, Discord-channels for support, and recorded lectures. The satisfaction of students with the use of digital tools in learning is shown to the left of Figure 2. Overall, positive satisfaction with digital tools (including *strongly agree* and *agree*) was 38.1% in 2020, 60.9% in 2021 and 41.2% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 23.8% in 2020, 17.4% in 2021 and 32.4% in 2022. Of the respondents, 38.1% in 2020, 21.7% in 2021 and 26.5% in 2022 were neither satisfied nor dissatisfied with the use of digital tools in the course.

Students were also asked to rate their satisfaction with the use of SLVs as the most used asynchronous digital tools during the course. The satisfaction of students with the use of SLVs is shown in the middle of Figure 2. Overall, positive satisfaction with asynchronous SLVs (including *strongly agree* and *agree*) was 80.0% in 2020, 91.3% in 2021 and 69.7% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 10.0% in 2020, 4.3% in 2021 and 15.2% in 2022. Of the respondents, 10.0% in 2020, 4.3% in 2021 and 15.2% in 2022 were neither satisfied nor dissatisfied with the use of asynchronous lecture videos during the course.

Students were also asked to rate their satisfaction with the use of Mentimeter and Flinga as synchronous interactive digital tools used during lectures. Mentimeter was used for interactive quizzes across students participating either physically or digitally in class, and Flinga used as an anonymous question board where both students participating physically and digitally could ask any question anonymously during lectures. The satisfaction of students with Mentimeter and Flinga is shown on the right in Figure 2. Overall, positive satisfaction with Mentimeter and Flinga

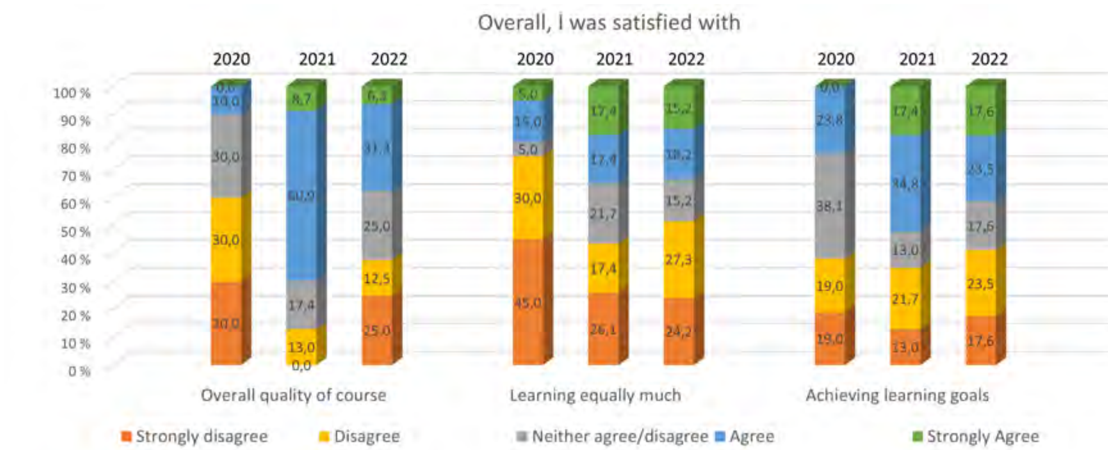

Figure 3. Overall satisfaction with the quality of the course (left), satisfcation with online learning compared to physical lectures (middle), and student satisfaction with achieving the overall learning goals of the course (right). Data shown for years 2020, 2021 and 2022 in each category. Respondents: 20 (2020), 23 (2021), 33 (2022).

(including *strongly agree* and *agree*) was 60.0% in 2020, 69.6% in 2021 and 57.6% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 25.0% in 202o0, 13.0% in 2021 and 6.1% in 2022. Of the respondents, 15.0% in 2020, 13.0% in 2021 and 36.4% in 2022 were neither satisfied nor dissatisfied with the use of interactive digital tools during lectures.

Overall satisfaction with online hybrid learning

Students were asked to rate their overall satisfaction the course. The satisfaction of students with the course is shown on the left of Figure 3. Overall, positive satisfaction with the course (including *strongly agree* and *agree*) was 10.0% in 2020, 69.6% in 2021 and 37.5% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 60.0% in 2020, 13.0% in 2021 and 37.5% in 2022. Of the respondents, 30.0% in 2020, 17.4% in 2021 and 25.0% in 2022 were neither satisfied nor dissatisfied with the quality of the course.

Students were also asked to rate their overall satisfaction with OHL as compared to only F2F lectures in the course, and if they felt that they had learned equally much with OHL as they would have with only F2F lectures. The satisfaction of students with OHL is shown on the middle of Figure 3. Overall, positive satisfaction with OHL (including *strongly agree* and *agree*) was 20.0% in 2020, 43.5% in 2021 and 33.3% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 80.0% in 2020, 39.1% in 2021 and 51.5% in 2022. Of the respondents, 0.0% in 2020, 17.4% in 2021 and 15.2% in 2022 were neither satisfied nor dissatisfied with OHL compared to physical lectures.

Students were also asked to rate if they had achieved the overall learning goals of the course through the OHL format. The satisfaction of students on achieving the learning goals through OHL is shown on the right of Figure 3. Overall, positive satisfaction with achieving the learning goals of the course (including *strongly agree* and *agree*) was 23.8% in 2020, 52.2% in 2021 and 41.2% in 2022, while negative dissatisfaction (*strongly disagree* and *disagree*) was 38.1% in 2020, 34.8% in 2021 and 41.2% in 2022. Of the respondents, 38.1% in 2020, 13.0% in

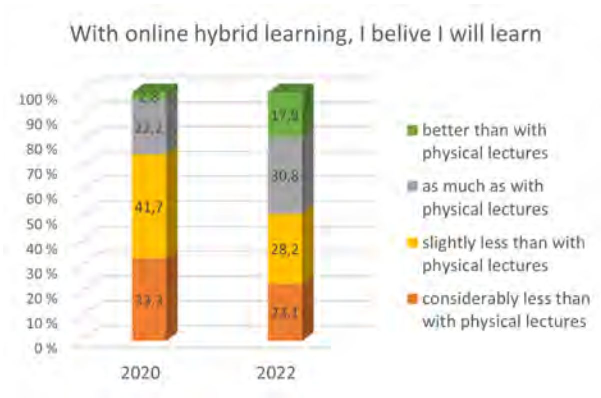

Figure 4. Expectations to OHL for students in year 2020 and 2022. Respondents: 36 (75.0%) in 2020, 39 (49.5%) in 2022.

2021 and 17.6% in 2022 were neither satisfied nor dissatisfied with how they could achieve the learning goals of through OHL.

Expectations to online hybrid learning

Students were also asked about their expectations to OHL through the anonymous polling feature in Zoom in the first week of the course as shown in Figure 4. Data for the year 2021 is regrettably not available. Of the respondents, 75.0% in 2020 and 51.3% in 2022 expected to learn less (including *considerably less* and *slightly less*) than with physical lectures, while 25.0% in 2020 and 48.7% expected to learn *as much* or *better* with OHL than with only F2F lectures.

Qualitative remarks to online learning

Students could also give written remarks to the OHL methods employed in the course. Relevant remarks have been anonymised and grouped, and are shown in Table 1.

Table 1. Statements from students to OHL

Statement	**2020**		**2021**		**2022**	
	Positive	**Negative**	**Positive**	**Negative**	**Positive**	**Negative**
Online vs F2F	Good (1)	Prefer physical (2), Physical always better (1)		Too few physical lect. (1), Physical always better (1), Poor (1), No relationship with lecturers (1)	Very good (2), Allows for repetition (1)	Prefer physical (12), Poor (2), No relationship with lecturers (1)
Short lecture videos (SLVs)	Good (8), More (1)		Good (4), Positive (1)	Only for repetition (1)	Good (4), Activating (1)	
General use of digital tools	Good (4)			Can improve (1)	Good (4), Activating (1)	PowerPoint gives poor learning (4), No use of blackboard (1)
Use of Mentimeter	Good (2)		Fun way to learn (2)	Unnecessary (1)	Very positive (1), Good (1)	
Use of Flinga	Good (1)		Good (1), Fun way to learn (1)	Unnecessary (1)	Excellent (2)	
Use of Discord	*(not used)*	*(not used)*	Good (1)		Good (2), Excellent (1), Positive (1)	Long wait for replies (1)
No. of pos. and neg. comments	**16**	**3**	**10**	**8**	**23**	**21**

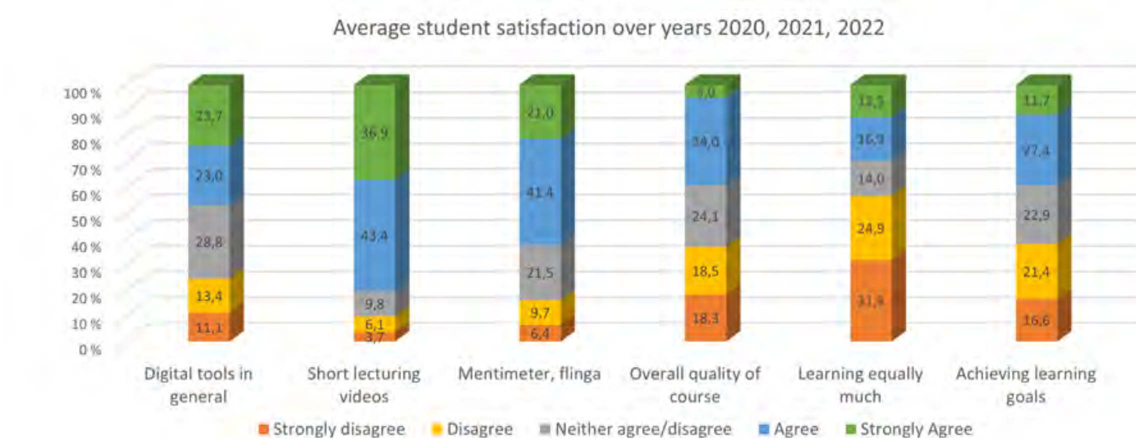

Figure 5. Average student satisfaction with OHL averaged over years 2020, 2021 and 2022 in each category.

DISCUSSION

Students were overall more positive than negative to the digital tools used in the course (46.7% vs 24.5%) when looking at averaged data over all three years as shown in Figure 5, and also very positive to the use of asynchronous SLVs (80.3% vs 9.8%) and to the use of the synchronous digital tools Mentimeter and Flinga during lectures (62.4% vs 16.2%). Students were, however, divided between being positive (39.0%) or negative (36.8%) to the overall quality of the OHC in Figure 5, and did not rate OHL equal to F2F lectures (29.4% positive vs 56.7% negative). Students were also divided with respect to achieving the learning goals of the course with OHL (39.1% positive vs 38.0% negative).

Students in the year 2020 were forced into an online learning situation by the COVID-19 pandemic and restrictions on social interactions, and had all of their SLAs online except for some physical lab sessions. Their expectations to OHL were low as seen in Figure 4, and only 25% expected to learn as much or better through OHL, while 75% expected to learn less than with F2F lectures. Students in 2021 had become more accustomed to the OHL format, and also received a third of lectures as F2F lectures due to the lift of restrictions on social interactions. Students seem to have accepted the situation of OHL, and responded consistently more positive on the use of digital tools in Figure 2 and on satisfaction with OHL in Figure 3 than students in years 2020 or 2022. Students in the year 2022 had higher expectations to OHL in Figure 4 than students in 2020, and also rated overall satisfaction with the quality of the OHL outcomes in Figure 3 more positively than in 2020. However, based on the number of negative remarks in Table 1, and also the lower positive rating of achieving overall learning goals to the right in Figure 3 in 2022 than in 2021 (41.2% vs 52.2%), there are indications of a polarisation among students between those who have come to appreciate the positive aspects of OHL, and those students that strongly prefer to go back to only F2F lectures. This can be supported by the results from Nortvig et al. (2018) where the learning outcome was seen to depend more on individual factors for each student than the inherent factors of the hybrid or F2F learning activities.

Students were overall more positive than negative to the use of digital tools during lectures. Short lecturing videos got very positive feedback on average (80.3%), but one student remarked

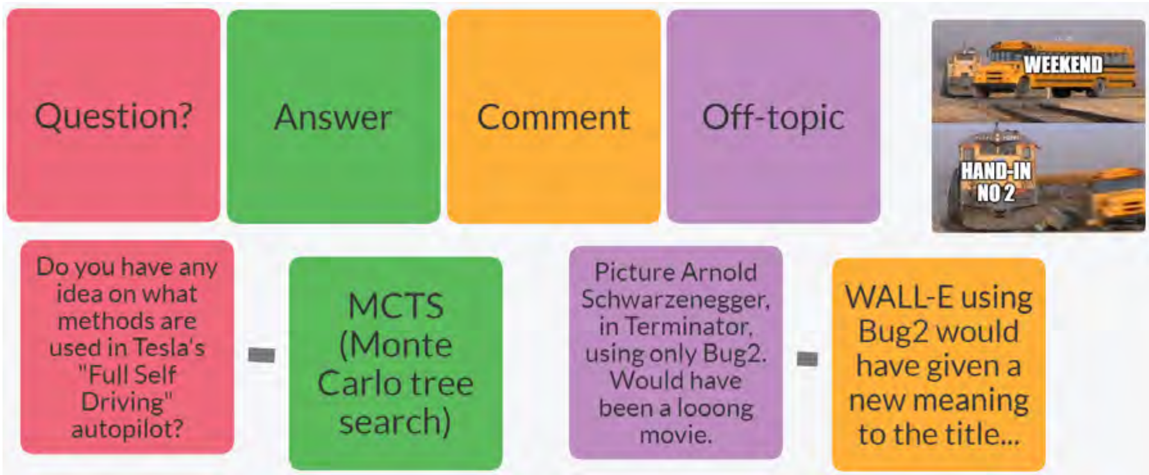

Figure 6. Example of Flinga anonymous discussion board from a lecture on mobile navigation (translated from Norwegian).

that the videos should only be used for repetition of material, and not for preparations (Table 1). Overall, videos were viewed as a very positive resource to the course, and also helpful in activating self-learning and making it easier to prepare for lectures. Mentimeter and Flinga as digital tools were also rated positively by students, and Mentimeter was described as a ”fun way to learn” and to be a positive student-active learning activity by students in Table 1. Flinga as an anonymous whiteboard for students to ask and comment anonymously was also rated positively by students. In some lectures, students took advantage of the off-topic category in the Flinga board as shown in Figure 6 to post memes commenting on the course, and had students laughing simultaneously at the same jokes across three campuses and across F2F and online attendance. The authors would also like to comment that online students became more active in discussions and in asking questions during lectures when Flinga was used for anonymous comments. However, one student remarked that similar features as Mentimeter and Flinga existed in Zoom, and that the use of additional tools was unnecessary. In 2021 and 2022, a Discord server was also set up to give support to students. This was overall positively rated by students from remarks in Table 1, but one student complained about having to wait too long before answers to questions were provided.

Overall, while students were positive towards the overall use of digital tools, they also remarked that there is room for improvement (Table 1), and that reading out loud from PowerPoint slides gives poor learning for students. Students remarked that they want more student-active learning activities in OHL, and that lecturers should use (digital) blackboards more in lectures to run through examples and exercises. This is also supported by the requirement for lecturers to prepare better for OHL found in Nikolopoulou (2022). However, students are also generally satisfied with the use of student-active digital tools such as Mentimeter and Flinga, which supports the recommendations in Kyrkjebø (2020). One of the biggest challenges with OHL for multi-campus courses is that the number F2F lectures are reduced for students at each campus, and they report in Table 1 that it is more difficult to establish a relationship with lecturers. These results are also consistent with the findings in Nortvig et al. (2018); Park (2011) where reduced interactions with lecturers is the most negative aspect of OHL. However, students also report, as in Nikolopoulou (2022); Nortvig et al. (2018); Park (2011), that time and space flexibility are very positive aspects of OHL.

CONCLUSION

The results presented in this papers suggests that there is still some way to go before OHL is evaluated as equal when compared to F2F lectures. In general, digital tools used for OHL are evaluated positively, and especially short lecturing videos and interactive tools such as Mentimeter and Flinga was evaluated as positive for student learning. However, students also reported that there is potential to make OHL activities even more student-active, and that lecturers need to take more care in preparing for student-active OHL activities than for F2F activities. Future work will look into how group projects can be even further developed to motivate self-supervised learning and more student-active learning strategies.

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SUSTAINABLE SYSTEMS ENGINEERING PROGRAM: MEETING ALL NEEDS WITHIN MEANS OF THE PLANET

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ABSTRACT

Across engineering education in Canada and the world, there is an increased recognition of the importance of sustainability mindsets, particularly since the adoption of the Sustainable Development Goals in 2015. Traditionally, sustainability within engineering has focused on the technical issues and taken a very end-of-the-line approach, for example looking at how to technically manage and reduce pollution (Tejedor et al., 2019). There is a growing recognition of the need to transition to a more holistic systems approach to more effectively address sustainability by considering the "complex, systemic interconnections and cause and effect relationships" (Sandri, 2013). This is also reflected within the CDIO Syllabus 3.0 section 4 which highlights the importance of systems engineering within societal and environmental contexts. At the University of Calgary, we developed a program in sustainable systems engineering from the ground up, where we intentionally imbedded a systems approach and a regenerative design mindset from the onset. In this paper, we provide an overview of the frameworks we have used to guide our program development. For example, the *engineering for one planet framework* (EOP, 2020) aims to "minimize negative impacts, strive to achieve at least net neutral outcomes, and, ideally, are restorative" (p.9). If we are to be truly transdisciplinary in our approach to solving complex challenges, we need to move from a human-centered to a life-centered approach. Overall, we hope to foster mindsets to develop engineering students who are able to fundamentally shift the discourse on sustainability engineering within industry, and critically reflect on the role of engineering itself. As engineers our responsibility is not only to society and culture, but also to nature and the planet. This program aims to provide students with the necessary skillsets to foster real change across engineering industries to better support the interrelated elements of our society and planet.

KEYWORDS

Sustainability, Systems, Engineering for One Planet, Environmental Justice, Program Development, Standards 3, 5, 7

INTRODUCTION

There are many calls to change sustainability education in engineering, and these calls are continuously becoming more urgent. As expressed in a recent Journal of Engineering Education editorial, it has become more evident that we need a fundamental change to the way we teach engineering. Specifically, engineering education needs (1) to acknowledge that engineering design is directly linked to the climate; (2) to be more interdisciplinary; (3) to take a social justice approach to engineering; and (4) to co-create with diverse communities (Martin et al., 2022).

Sustainability education in engineering has rapidly increased over the last couple decades (Thürer et al., 2018), although much of this education focuses on economic and environmental sustainability, with little focus on social sustainability (Reynante, 2022). Even the most successful efforts in integrating sustainability across a curriculum still find barriers on sustainability being considered a “soft” skill that is not valued in engineering, and no one willing to take ownership over the sustainability content. Reynante (2022) provides a clear outline in their comprehensive literature review of the continuing mindsets and ideologies that marginalize sustainability efforts in engineering education which include: positivism and objectivity, reductionism, technical-social dualism, techno-solutionism, and consumerism and materialism.

The CDIO syllabus also recognizes the importance of this change in mindset towards the way we teach engineering, including the following examples within section 4 (the innovation process) of the CDIO Syllabus 3.0 (Malmqvist et al., 2022; CDIO, n.d.):

- 4.3.1 Needs vs. wants with respect to justice and sufficiency
- 4.3.1 Understanding conditions for operating within planetary boundaries
- 4.4.6 Design for Circular Economy

There are many approaches to change in engineering education (see Reynante, 2022). At the University of Calgary, we developed and are now implementing an entire new program called the Sustainable Systems Engineering Program (Paul et al., 2021, Paul & Eggermont, 2022). In this paper, we will provide a discussion of our rationale and mindsets in the development of the program, as well as an overview of the program design.

BACKGROUND LITERATURE

Integral to the design of the new sustainability program was incorporating literature that informed the mindsets across the program curriculum. Specifically, here we discuss the Engineering for One Planet framework, and the importance of integrating justice approaches.

Engineering for One Planet

“Principles of Environmentally Responsible Engineering: Creating a Roadmap for Change” was a roundtable attended by the author in 2019 which led to becoming a contributor to an initial Environmentally Responsible Engineering (ERE) Definition and Framework to being a member of the Engineering for One Planet (EOP) Design Team from 2020 to 2022. Now known as the EOP framework, it is defined as follows:

> The EOP framework outlines the cross-cutting knowledge, awareness and competencies needed to design, build, manage and implement engineering solutions that minimize negative impacts, strive to achieve at least net neutral outcomes, and, ideally, are restorative. EOP will enable engineers to be better equipped to create positive outcomes for the planet and the life it sustains, now and for future generations, and to help ecosystems recover and thrive when possible. Rather than a new discipline, EOP comprises the fundamental

learning outcomes that every graduating engineer —regardless of subdiscipline, institution, identity, or geography— needs to acquire to excel as engineers operating within our planet's constraints. By possessing the basic knowledge, understanding, skills, experiences and behaviors of EOP, future engineers will be prepared with the competencies to ensure that engineering disciplines do not inadvertently harm but seek to enhance the well-being of humans and the living planet. (EOP, 2020)

The EOP framework (see Figure 1) has systems thinking at its core teaching students the ability to identify and understand interconnectedness and how all human-made designs rely upon and are embedded within ecological systems. In addition, it touches on feedback loops, tipping points, and system resilience. The program aims to foster students with the skillsets necessary to consider outcomes of present engineering design decisions on future generations. In understanding tradeoffs and identifying impacts between different parts of the system it reminds one of Kate Raworth's Doughnut Economics (Raworth, n.d.), meeting the needs of all (the social foundation) within the means of the planet (the ecological ceiling).

The framework includes skills recognizable for any engineering program such as leadership, teamwork, and critical thinking, all while emphasizing the role of environmental responsibility. Design, materials choice, and environmental impact measurement are listed as key technical skills but pays attention to understanding environmental and social impacts of others' designs and setting goals to minimize environmental impact. Where it expands most on current engineering curriculum is in the knowledge and understanding category of the framework. Environmental literacy, responsible business and economy, and social responsibility in this domain add several interesting and relevant education pieces for future engineering students. Advanced concepts such as an awareness of key environmental laws, ethics and policies at the regional, national, and global levels, an ability to consider ethical implications beyond current compliance and political boundaries, and knowledge of ecosystems services are a few of the key knowledge-based pieces that the framework recommends in order to educate a new breed of engineers.

New business models, such as models that leverage product durability are closely tied to design and encourages teaching design for circularity. The 9Rs (which may be up to 12 now) help to promote the idea of circularity: refuse, rethink, reduce, reuse, repair, refurbish, remanufacture, repurpose, recycle (Khaw-ngern et al., 2021). This, along with an awareness of emerging economic systems intended to promote environmental and social responsibility in economic thinking ties back to systems thinking and doughnut economics.

Our students need to be aware as global citizens of social and cultural implications related to local, regional, and global materials use and learn to recognize that impacts are disproportionately borne by low income and minority groups.

Current and past engineering mindsets and ideologies that marginalize sustainability will have to start taking a backseat if we want our species to survive. This includes - among other mindsets - not perpetuating the current techno-social dualism and techno-solutionism: that the social is irrelevant and the belief that technology can unilaterally solve complex social and environmental problems (Reynante, 2022). Time to leave the comfort of the quantifiable and dip our toes in the messy, unreliable, data-skewing externalities of the qualitative.

Figure 1. Engineering for One Planet framework (EOP, 2020)

Environmental Justice in Engineering Education

Around the world there are many examples of how engineering has played a significant role in environmental degradation that disproportionately impacts black, indigenous, and other minoritized identities. For example, even though Shoal Lake has provided drinking water for the city of Winnipeg for over a century, it wasn't until 2021 that the Shoal Lake 40 First Nation's community was provided with safe drinking water. Not only that, but the engineering decisions making an aqueduct at Shoal Lake isolated the indigenous community making it impossible for them to travel (Perry, 2016). In the United States, the Flint water crisis is another example where since 2014 elevated levels of lead have been found in the water system due to engineering decisions and mistakes (Masten, Davies & Mcelmurry, 2016).

These are only two examples of how essential of a role engineers play in environmental justice, and how traditionally these social justice considerations have been left out of engineering decision making. Rather a “path of least resistance” approach is typically taken during engineering problem solving, which tends to impact minority and poor communities most negatively (Ramirez-Andreotta, 2019). Not only this, but analysis has shown that engineering education has had very limited adoption of environmental justice education compared to other departments, even though engineering has been such a significant contributor to environmental injustices (Wilson-Lopez, Taylor & Santiago, 2022).

Through our program design we hope to learn from scholars in the area who are integrating environmental justice into engineering education using intentional pedagogies (Wilson-Lopez et al., 2022; Bielefeldt & Silverstein, 2021). Many have begun to understand the importance of systems thinking in the context of sustainability in engineering and social justice in engineering (Martin et al., 2022; Reddy & Mancus, 2021). Additionally, there has been much discussion on the importance of project-based learning and community-based learning as transformative learning pedagogies to support the development of the necessary skills in sustainability engineering and environmental justice (Faludi & Gilbert, 2019; Reynante, 2022).

PROGRAM DESIGN: SUSTAINABLE SYSTEMS ENGINEERING

“I hope you are doing well and enjoying the nice weather! I was hoping to grab a bit of your time to chat about sustainability initiatives.” This innocent email from September 2020 started a 2-year design deep dive and resurfaced as a new undergraduate major which will welcome its first cohort in September of 2023. An interdisciplinary group representing all engineering departments including undergraduate and graduate student representatives was tasked with designing a ‘lean’ sustainability program. We accomplished this by integrating core engineering courses from across the school and integrating among other things sustainability principles, regenerative design, and land-based and experiential learning:

1. Systems thinking (Holistic Principle)
2. Respect for energy & natural resources (Conservation Principle)
3. Respect for people (Human Vitality Principle)
4. Respect for place (Ecosystem Principle)
5. Learning from natural systems (Biomimicry Principle)
6. Respect for future (“Seven Generations” Principle) “In our every deliberation we must consider the impact of our decisions on the seventh generation.” (McLennan, 2004)

In addition we created a design for sustainable systems spine that runs through all four years of the program. This is in line with CDIO Standard 5 which emphasizes the importance of Design-Implement experiences. Specifically, CDIO Standards supported understanding of the importance of structuring the courses as sequential learning experiences to reinforce students’ learning at increasing levels of complexity.

A full curriculum is shown in Figure 2, and in this section we will provide a broad overview of each year of the program, as well as highlight unique courses which we believe showcase the incredible interdisciplinary program design that aims to change the culture and beliefs around sustainability in engineering.

YEAR 1	
FALL TERM	WINTER TERM
CHEM 209: General Chemistry for Engineers	ENGG 201: Behaviour of Liquids, Gases and Solids
MATH 211: Linear Algebra 1	PHYS 259: Electricity and Magnetism
MATH275: Calculus for Engineers and Scientists	MATH 277: Multivariable Calculus for Engineers
ENGG 225: Fundamentals of Electrical Circuits and Machines	ENGG 202: Engineering Statics
ENDG 233: Computing for Engineers	ENGG 200: Engineering Design and Communication
	Complementary Studies Course I
YEAR 2	
FALL TERM	WINTER TERM
SUSE 301: Sustainable Systems Ecology	
SUSE 315: Engineering economics and decision making for sustainability	CHEM 321: Environmental Chemistry
ENDG 319: Probability, Statistics and Machine Learning	SUSE 311: Engineering Thermo-dynamics and fluid mechanics
MATH 375: Differential Equations for Engineers	ENGG 349: Dynamics
ENCI 317: Mechanics of Solids	SUSE 303: Signals, Instrumentation, and Data
SUSE 307: Numerical Methods and Computing Tools for Sustainable Systems Engineering	SUSE 300: Introduction to Sustainable Systems Design
AUGUST FIELD SCHOOL	
SUST 403: Sustainability Research Methods	
SUSE 401: Remote Northern Sustainable Systems *or* SUSE 403: Northern Sustainable Systems	
YEAR 3	
FALL TERM	WINTER TERM
SUSE 409: Regenerative Design Principles and Indigenous Knowledge Systems	ENEL 487: Electrical Engineering Energy Systems
ENEE 355: Introduction to Energy and the Environment	ENEE 575: Renewable Energy Systems
ENCI 481: Environmental Engineering	ENME 461: Foundations of Mechatronics
ENGG 461: Geospatial Data Analytics	SUSE 463: Systems modelling, Simulations, and analysis
Complementary Studies Course II	SUSE 400: Design of Sustainable Systems
YEAR 4	
FALL TERM	WINTER TERM
ENEE 503: Life Cycle Assessment	ENGG 502: Capstone
ENGG 481: Technology and Society	ENGG 513: The Role and Responsibility of the Professional Engineer in Society
ENGG 501: Capstone	Engineering Technical Elective
Approved SUSE Program Course	Engineering Technical Elective
Approved SUSE Program Course	Approved SUSE Program Course

Figure 2. Sustainable Systems Engineering curriculum

Years 1 and 2 of the program are a foundation for engineering and sustainable systems. This builds on many existing courses, as at our institution, all first-year courses are common, and many second-year courses are common to provide students with foundational engineering knowledge and skills.

Although at first glance, there is perhaps a feeling of the curriculum being a crash course in all engineering subjects, we want to highlight two intentional choices behind this design. Firstly, the goal of the program is to create a broad knowledge foundation focussed on the “system of engineering”. By broadly covering topics from all disciplines we are able to achieve this. Additionally, we are able to tied together the varied disciplines into the life-centered sustainable systems view through the design spine courses (most notable SUSE 300 and SUSE 400), and the SUSE core courses (SUSE 301, 401/403, 409 and a number of 500-level technical electives). Secondly, a long term goal is to infused the worldview across all disciplines – so although students in the SUSE program will specialize in sustainable systems, we want all graduates (electrical, mechanical, chemical, etc.) to take courses which emphasize life-based sustainable systems approaches. By collaborating with the departments across the engineering faculty in creating SUSE required courses, we hope to achieve this.

SUSE Specific Courses

In between years 2 and 3 students can take a *Remote Northern Sustainable Systems* field course in which they learn key ideas and strategies related to environmentally sustainable community development with a focus on food, water, and energy. Through pattern and data mapping, research and data analysis, and site visits, the students in the field course will explore community needs and the challenges of environmentally conscious living. The renewable energy systems at the field station will be investigated along with energy usage. Learners delve into the common misconceptions that lead to unsustainable social practices and how to counteract these fallacies through community education and engagement. A second option, *Northern Sustainable Systems*, teaches key ideas and strategies related to environmentally sustainable community development with a focus on net zero communities and geo-powered communities, exploring renewable energy systems at various sites and integration into local and community energy networks. These integrated learning experiences (CDIO Standard 7) will allow students to apply their professional and technical engineering knowledge, while simultaneously building personal, interpersonal, and systems thinking skills.

Year 3 is in preparation of SUSE themes which require knowledge, awareness and competencies needed to design, build, manage, and implement engineering solutions that minimize negative impacts, strive to achieve at least net neutral outcomes, and, ideally, are restorative. Students continue to take courses that are interdisciplinary, so as we move into implementation of these courses, it will be essential to ensure the curriculum remains integrated and students are able to understand the disciplinary linkages (CDIO Standard 3: Integrated Curriculum).

In year 4, students can tailor their program and focus on one of four themes:

- Sustainable systems for Environment
- Sustainable systems for Communities and Cities
- Sustainable systems for Energy and Resources
- Sustainable systems for Food, Agriculture, and Biomass

There are three courses which highlight the unique aspects of the SUSE program and its design. Firstly, the *Sustainable Systems Ecology* course is taken at the beginning of year 2 which introduces students to upper year possibilities and is a preview of the four theme areas. This short 5-day course is an introduction to macroecology for sustainable systems, including theory, tools, and techniques. It introduces students to systems thinking and program theme areas through design projects and ‘campus as a learning lab’ workshops.

Another course highlight is the *Introduction to sustainable systems design* course which students take in their second semester of year 2. This course introduces students to systems thinking, design for a circular economy, tools for sustainability and regenerative engineering, and concepts of design for justice. The course uses collaborative and creative practices to address the deepest challenges our communities and environments face, centering on the voices and habitats of those who are directly impacted by the outcomes of the design process. In addition, systematic design methods are introduced as part of community-engaged projects.

Finally, a particularly unique course is a non-standard course (meaning a concentrated one-month schedule) called *Regenerative Design Principles and Indigenous Knowledge Systems.* In this course, students will explore principles of regenerative design and systems thinking through an Indigenous Knowledge Systems lens, and whole systems thinking to create resilient and equitable systems that integrate the needs of society with the integrity of nature. Topics that will be explored are grounded in Indigenous methodologies and epistemologies and explore Indigenous Knowledge and the intersection of sustainability science in a culminating land-based learning experience.

CONCLUSION

Overall, we hope to foster mindsets to develop engineering students who are able to fundamentally shift the discourse on sustainability engineering within industry, and critically reflect on the role of engineering itself. As engineers our responsibility is not only to society and culture, but also to nature and the planet. This program aims to provide students with the necessary skillsets to foster real change across engineering industries to better support the interrelated elements of our society and planet. We aim to accomplish this both through using theoretical foundations in the development of the program, including Engineering for One Planet framework and environment justice, and applying unique pedagogies to the courses. Long term, we hope by co-creating these courses with disciplines from across the engineering faculty, that the life-centered engineering worldview core to the SUSE program will begin to be integrated and fundamental to other engineering programs as well. The first set of students will be entering the program in Fall 2023, and we look forward to co-creating transformative learning experiences with them.

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EXPERIENCES FROM IMPLEMENTING A SCHOLARSHIP OF TEACHING AND LEARNING PROGRAM FOR TEACHERS

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ABSTRACT

Teaching quality is essential for having a high standard of educational quality. To achieve this, teachers need to be supported in their professional development.
Scholarship of Teaching and Learning (SoTL) is a way to support teachers in the development of their teaching practice as SoTL is the systematic study of teaching practices and learning experiences with the goal of improving students learning. In SoTL, the focus is on a scholarly approach to teaching and learning, where teachers act like researchers to investigate and develop their own teaching practice. The teachers work systematically with continuous improvement of their teaching and investigate the teaching impact and how it supports the students learning. SoTL also involves reflection on their own teaching practice. Furthermore, it adds a possibility to contribute the accumulated knowledge to the ongoing discussion about the development of engineering education by participating in conferences within Engineering Education Research and to publish scientific articles in relevant journals as well as networking with other teachers and educational consultants around the world within Engineering Education Research.

Since 2018, we have been running a SoTL program for teachers at our institute. Each year a number between 10 and 20 teachers have participated in the program. The SoTL program is scheduled to take a year, and consists of seminars with external and internal presentations, workshops and work with own projects. Furthermore, the program consists of feedback sessions with the program leader and peer-to-peer feedback sessions.

The participants must come up with a question, “a teaching problem”, which is something they are curious about in their teaching and want to investigate. During the SoTL program, each participant makes a research design, collects, and analyzes data and at the end of the program makes a presentation of the results from the project. Furthermore, the participant is encouraged to participate in educational conferences.

In this presentation, we will present our findings from three times running a SoTL program for teachers. Furthermore, we will present and discuss the challenges of implementing a SoTL program for teachers.

KEYWORDS

Teaching, learning, scholarly, standards (10, 9, 8, 7)

INTRODUCTION

Teaching quality is important for achieving and retaining a high standard of educational quality. Thus, the teachers need to be supported in their professional development. Therefore, it is important to create opportunities for teachers to collaborate, to share knowledge and to do practice-based research to promote educational development. In addition, it is important to provide the teachers with tools to continually develop their teaching practice and to enhance their understanding of student's learning.

The Scholarship of Teaching and Learning (SoTL) is a framework for university teachers to develop their teaching as well as ensure the quality of the teaching. Furthermore, it is a training for the teachers to become scholarly teachers.

The concept of SoTL was developed by Boyer (1990) and his concern was to address the disproportionate status reward accorded to research in universities, and the consequential disregard for the importance of teaching. Boyer (1990) proposed a reconceptualization of the activity of the university, arguing that it was best seen as embracing four distinct but interdependent and interrelated forms of scholarship: discovery, integration, application, and teaching. In this paper, we will focus on the form Scholarship of Teaching. Since Boyer first proposed his idea a variety of SoTL models have been launched (Trigwell & Shale, 2004) and the SoTL framework today is used by practitioners around the world (Mårtensson et al. 2011).

The SoTL framework offers a way to approach teaching and learning scientifically with focus on identifying and defining a problem, systematically gathering evidence of student learning, and drawing conclusion from the evidence and making results public for peer-review purposes (Dewar et al., 2018; Mårtensson et al 2011).

The SoTL framework can be a way to focus on educational development and be a support for academics to set up and maintain a high standard of teaching and learning. This can lead to enhancement of faculty teaching competence (CDIO standard 10) as participating in SoTL include actions with enhance faculty teaching competence as SoTL is a development program, a forum for sharing ideas and best practice among the participants. In addition, the assessment of students learning (CDIO standard 11) is relevant as many SoTL projects have focused on the extent to which each student achieves specified learning outcomes.

The SoTL framework can be a way to support teaching as a subject for research where the teacher has a scholarly approach of teaching and learning, which include making research about own teaching and go public at conferences with results to share and thus receive feedback (Graham. 2018). In addition, SoTL framework can help the university to build a community with focus on engineering education at the university and can be used as the development of the university's ability to support student learning (Mårtensson et al., 2011). At Twente University in Holland, they have developed a scholarly approach regarding the senior University Teaching Qualification where the participants work as researchers to investigate their own teaching (Poortman et al., 2020).

The benefits of participation in a SoTL program, are that it promotes a more reflective teaching and improve the teaching effectiveness (Dewar et al., 2018). SoTL is described as having three main benefits. First, engaging in SoTL improves the student learning because it affects how the teachers think about teaching and the learning opportunities for their students. Second, contributions to the field of teaching are improved and enhanced. Third, engaging in SoTL enriches one's experience as a teacher (Bishop-Clark & Dietz-Uhler,2012).

According to Bishop-Clark & Dietz-Uhler (2012), the SoTL framework consists of five steps, 1) Identify the research question, 2) Design the study, 3) Collect the data, 4) Analyze the data and draw the conclusion and 5) Present and publish the SoTL project. This is illustrated in figure 1.

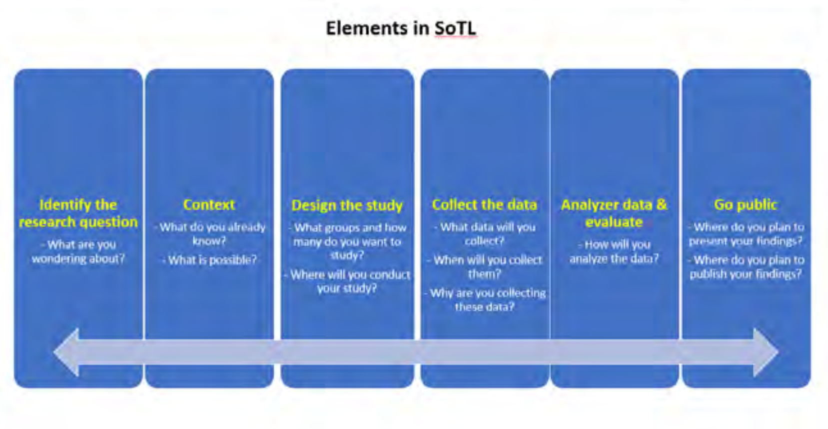

Figure 1: Elements in SoTL program at DTU

Felten (2013) has described the principles for good practice in SoTL:

1) Inquiry focused on student learning
2) Grounded in context
3) Methodologically sound
4) Conducted in partnership with students
5) Appropriately public

Normally, inquiry into learning has focused on the students, but it can also include explorations of how teaching and a teacher influence affects the students learning (Biggs, 1999). To be scholarly, builds on what is known and using relevant theory. Good practice in SoTL requires application of research tools that connect the research question to student learning and is conducted in partnership with students (Felten, 2013). Good practice in SoTL requires that both the process and the product of the research are public so colleagues can give feedback and use the SoTL work (Felten, 2013).

The SoTL program at DTU focus on the scholarly approach of teaching and learning, where the teachers are researcher and design their own research plan to be able to investigate their own educational practice with the aim of improving teaching and support the students learning. The SoTL program consists of two parts. One part consists of presentations and workshops held by internal and external experts. The purpose of the first part is to give the participant knowledge and inspiration on how to investigate elements in their teaching and which methods they can use. In the other part, the SoTL participants plan and execute their own project either alone or in smaller groups. During the project they are supported by internal and external supervisors and peer feedback from colleagues. In Figure 2 the plan for the SoTL program at DTU is shown.

After running the SoTL program three times, this paper describes the benefits and the challenges of running a SoTL program. Furthermore, improvements for the future SoTL programs will be introduced.

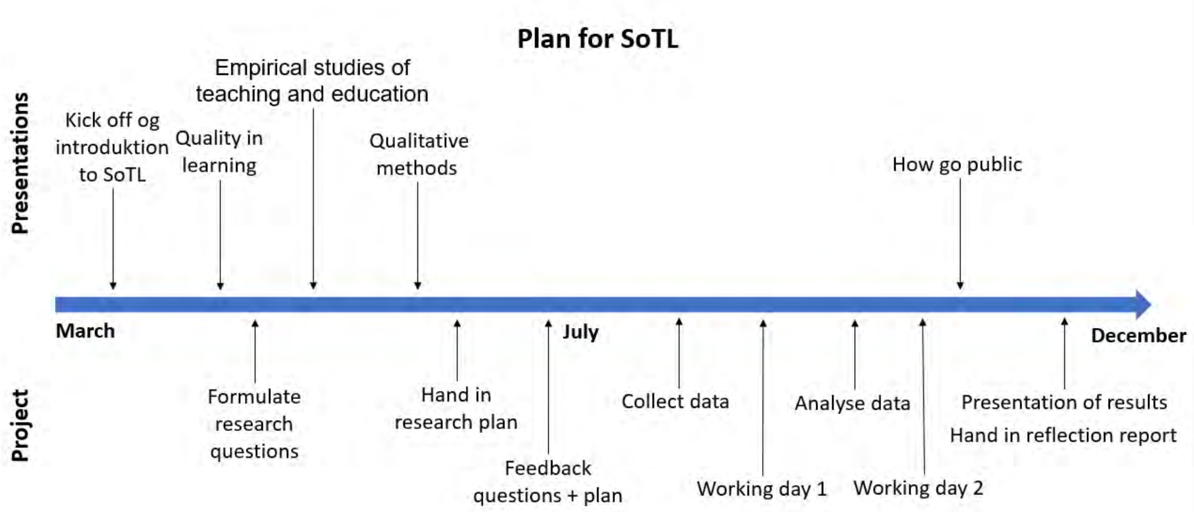

Figure 2: Overview SoTL program DTU

The research question is how to develop a program on a scholarly approach of teaching and learning. Furthermore, to present and discuss the challenges of implementing a SoTL program for the teachers.

FRAMEWORK AND DESIGN

The Scholarship of Teaching and Learning program at DTU

At the Technical University of Denmark (DTU), in the Department for Engineering Technology and Didactic (DTU Eng Tech) we have been running an internal program based on the SoTL framework three times (2018, 2021 and 2022).

Participants in the SoTL program at DTU Eng Tech are all experienced teachers at the institute and when participating in the SoTL program, they are expected to:

- Be motivated to and have a focus on how to improve their teaching.
- Be critical and proactive with regards to their own role as teacher.
- Be actively involved in the activities in the program and to collaborate with other participants in the SoTL program.

Each participant received 70 hours from the institute (internal hours) to use for the SoTL program. Further hours for their individual project might be needed and extra hours are therefore expected to be provided by their research group.

The experiences from running the SoTL program will be presented and discussed.

SoTL 2018 program

The first SoTL program in 2018 was a pilot study. Ten teachers from one department at the Institute participated in the pilot program. The participants were mainly associate professors with several years of experience as university teachers.

The aim of the pilot program was to find a structure for a SoTL program. External presenters gave motivating talks concerning different aspects of SoTL to motivate the participants to work with their own teachings. In the pilot program there was only a little focus on the participants' own project, but some of the participants did small studies into their teaching, which they presented at the end of the program.

SoTL 2021 program

In February 2021, we started the next SoTL program. To attend the program in 2021, the teachers were asked to write a small application with a description of which course to work on and what they wanted to investigate in their individual project - what was she/he interested in and wanted to explore during the course.

A total of ten teachers participated and all of them were associate professors with many years of experience as university teacher.

The first meeting – the kick-off meeting was held in February and was an introduction to the SoTL framework, but there was also time for the participants to get to know each other. Furthermore, the participants pitched their topics of interest, and they received feedback from the other participants.

In the first half year (until summer) there were meetings every month with presentations and workshops. The meetings were focused on explaining the processes of educational design, how to get data, how to analyze data etc. Most of the talks were held by external speakers within the field. All meetings were scheduled to be a three-hour meeting and were held every month.

Three months after the start, the participants started to work on their own projects. The participants could work alone or in groups of two-three teachers. The participants started to formulate their project and describe which problem they want to investigate in. They could use their initial idea, but they could also choose another subject. Each participant/group made a research plan which they handed in and then got several feedbacks from the peers and the facilitator.

When the new semester started in September, the research plan was ready, and the participants started to collect data for their own projects. During the autumn semester data was collected and then analyzed.

During the last period of the project, the participants additionally met at lunch meetings to discuss their project and possible challenges etc. Furthermore, each participant could ask for an individual feedback meeting with the facilitator.

At the end of the SoTL project 2021, there was a poster session, where the participants presented their results to their colleagues at the institute. At the poster session they received feedback from colleagues and the management team at the institute. Furthermore, the participants were encouraged to write an abstract and/or a paper for a conference within the field of Engineering Education Research or for a journal.

SoTL 2022 program

In the SoTL 2022 program, 13 participants were enrolled. This time the participants consisted of PhD students, assistant professors, and associate professors. Some of the associate professors had many years of experience as university teachers while other associate professors had many years of experience as researchers. The structure from the SoTL program in 2021 was followed with a few adjustments.

OUTCOME

After running the SoTL program three times, the SoTL program has now been implemented as a competence development program for all teachers at the institute. The implementation of SoTL is supported by management and each participant receives 70 hours (internal hours) for participation in the SoTL program. The teachers can follow the SoTL program several times.

The participants worked on a large variety of themes like "formation of groups – self-selected or decided by the teacher", "choice of case for case work - should it be decided by teacher or students?", "how to strengthen student motivation" and "how to facilitate different groups of students". All themes are related to the participants own teaching.

SoTL 2018 outcome

The aim of the pilot project in 2018 was to develop a structure for a SoTL program. External presenters gave motivating talks concerning different aspects of SoTL to motivate and inspire the participants to work with their own teaching. Five presentations were held during 2018 with one meeting every month (not during the summer period). In the pilot project, there was only little focus on the participants' own project, i.e. some of the participants did small studies into their own teaching which they presented at the end of program. The results from the pilot program were evaluated based on the organizers' perceptions and comments from the participants. It showed that the teachers were highly motivated to participate in a program like SoTL and they were also interested in working with their own teaching. Besides the input from the teachers, we also got knowledge about what could be relevant for future teaching materials and which subjects at present were relevant to participate in. In addition, it was clear that more time should be assigned to the participants if they should work with their individual projects.

Based on the results from the pilot program, a program with internal and external presenters and a plan for how the participant should work with their own project was developed. Unfortunately, due to the covid-19 situation, the next SoTL project was not launched before 2021.

SoTL 2021 and SoTL 2022 outcomes

In the SoTL program in 2021, we had a program with seminars and workshop planned for the entire year based on the input and observations from the pilot program in 2018. Furthermore, teachers from the whole institute were invited to participate and the teachers had to write an application before enrollment into the SoTL program.

Based on the comments and observations from the SoTL 2021 the program for SoTL 2022 was made. Only small changes were made like it was mandatory to hand in the research plan for feedback.

The reflections from running the SoTL program in 2021 and 2022 were that the application before enrollment worked well as it started the reflections about what to investigate and why it could be relevant to do so. All the applicants were accepted to the SoTL programs in 2021 and in 2022, these participants were more prepared and focused than the participants were in the 2018 program. The participants were motivated to work with their teaching, and they appreciated networking with the other participants. Networking was mentioned as an important output. Poortman et al (2020) mentioned in their paper that recognizing and rewarding teaching is essential to support effective professional development and a practice for this should be considered for the future program. Today the participants received a diploma after their poster presentation.

The participants learned how to present their improvements in posters, abstracts and papers. All participants had to do a poster presentation held at the end of the program. Furthermore, some participants have written a journal paper and/or participated in conferences with engineering education research. One participant from the program in 2021 presented his work at the SEFI Conference in 2022 (Schultz & Blaszczyk, 2022) and another participant from the program in 2022 is expected to submit a paper later in 2023.

A challenge was to have enough time for doing the collection of data and then to analyze them. Even though each participant received 70 hours, it was not enough for all participants. In the study by Poortman et al. (2020), it was also mentioned that the participants had difficulties in finding time for the activities.

Furthermore, for several of the participants it was their first time conducting social science (doing interviews with students etc.) and they had to learn to conduct interviews, observations etc. Furthermore, it also took some time to recognize what kind of data was available and what data needed to be collected.

One of the aims of the SoTL program was also to build a community about teaching and learning where the participants could meet after the SoTL program was finished. The community should help to create a culture for continuous improvement of teaching, and where teachers can share knowledge and inspire each other. This community still needs to be developed.

Based on the experiences of running the three SoTL programs the following improvements will be made.

In future SoTL programs, each participant is expected to deliver the following products: 1) a poster presentation, 2) a reflection report (main learnings from participation in the SoTL program). As an additional delivery it will be possible to hand in an abstract for a poster or a paper for an educational conference. The report will be reviewed by the project leader and the participants director.

In the 2022 program, it was not mandatory to hand in the research plan. Most of the participants did it, but in the future, we will make it mandatory to hand in the research plan after two months' time. The research plan will be reviewed by one of the facilitators to ensure that all its participants have a complete and a well-structured research plan before data collection starts.

To support the participants in their work on their project we will have several open sessions where the time is booked to work on the research plan, analyzing data or writing the report. It will be possible to get just-in-time feedback from the facilitator but otherwise the time is allocated for the work with the SoTL project.

CONCLUSION

After running the SoTL program three times the content and the structure of the program seems to be on the right track, and the SoTL program is now implemented as a competence development activity for the teachers at the institute. In the next program (2023), the expectations of the participants will be made clearer, and they are also supposed to submit at the end of the SoTL program. There will also be more focus on the creation of a community (for new and old participants) and having more scheduled work meetings to help the participants to better allocate time to their projects.

The participants are very positive towards SoTL, and they have expressed that participation in a SoTL program has had a positive impact on their thinking, teaching approach and their students learning.

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BIOGRAPHICAL INFORMATION

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Hanne Løje has for several years worked with didactics and pedagogy and has presented results at national and international conferences within Engineering Education Research and been project leader for several projects within this field. Hanne Løje has been teaching university students for more than 15 years and is responsible for development and running a number of new courses at DTU. Through her academic career, she has worked systematically with development of teaching, teaching materials and teaching environment to improve the students learning and she has published several papers in this context and presented her research at several international conferences.

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ENABLING LIFELONG LEARNING BY USING MULTIPLE ENGAGEMENT TOOLS

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ABSTRACT

This study aims to identify effective engagement tools and strategies that may strengthen student learning processes with a long-term impact. The context of learning plays an active role in student performance and needs to be carefully considered when designing collaborative learning environments. In the framework of a CDIO course entitled Project Course in Applied Physics (12 ECTS), master's students in applied physics, electrical engineering, biomedical engineering, material science and nanotechnology work in groups of four to seven people for realizing their own project idea given three broad requirements: (i) use gas sensors, (ii) manage a certain maximum budget to purchase components, and (iii) build a working prototype for any indoor air quality monitoring application of interest for them and their customer. Groups are generally multicultural and multidisciplinary. Qualified supervision and skills training activities are adapted to facilitate the students' progress and guarantee the success of their project work. Based on observations, feedback, and results over a five-year period, this approach appears more engaging and inspiring for both students and teachers compared to more defined projects. Encouraging the students to conceive their own original ideas, involving them in the co-creation of the learning process, and building knowledge, understanding, and skills through a variety of engaging experiences, helps their motivation, interest, active participation, and creativity with a direct impact on the quality of their learning. As an example of successful project work, here we report on two groups of students at Linköping University, Sweden, who have recently designed, developed, and tested an innovative sensor system prototype for smart monitoring of gas and particle emissions from cooking activities. The project course has received 5.0/5.0 as an overall students' evaluation.

KEYWORDS

Lifelong learning, Experiential learning, Active learning, Skills training, Multicultural environment, Engagement, Standards: 1, 2, 5, 6, 8, 11

THE CONTEXT OF LEARNING

In light of experiential learning theory (Kolb, 1984), learning is 'the process whereby knowledge is created through the transformation of experience'. Therefore, people learn from experience and through it, during their whole life, they acquire their own learning strategies which help them to face daily situations and solve problems, but also influence their behaviors and decisions. Each person has its own personal cognitive styles, also called “learning styles”, which may differ depending on, e.g., culture, age, or gender (Barmeyer, 2004), and may contain both strong and weak points (Jonassen and Grabowski, 1993). According to Hofstede (1986), our cognitive development is determined by the environment where we grew up, and our skills are shaped and reinforced in relation to the patterns of a specific society, consisting of family, school and university, work environment, and community. Many studies insist on the importance of culture and its impact on the students’ learning process. Nevertheless, culture is not deterministic: individuals are an expression of their native culture, but also a product of dynamic and continuous interactions with the environment where they live, at home or abroad (Signorini et al., 2010). The individuals simultaneously modify and are modified by the environment while fitting themselves in it. Adaptation to external conditions belongs to the learning process, therefore, the latter may be negatively affected when adaptation does not occur due to, e.g., the individual’s resistance to a situation or change (e.g., because it causes uncertainty or reconsideration of the own habits). Some studies suggest that students in intercultural educational settings are able and willing to change and behave differently in response to demands and teaching styles in the new educational context. However, these changes are not uniform. They vary between individuals also based on their expectations, views, knowledge, skills, attitudes, current and past experiences. International students are, on average, more inclined to adapt to changing conditions, as moving abroad is their own choice, but not always national students are willing to adapt to an international context that they have not chosen. Therefore, higher educators in each specialization area are responsible for ensuring that the learning processes and methods they use have elements that students from different cultures and backgrounds can understand and accept (Joy and Kolb, 2009).

Conceptually, culture is considered to reside both in groups and individuals, and it is often associated with national differences. However, in today’s globalized world, culture cannot be simply equated to the concept of “nation” as it can no longer be confined to a physical space (Signorini et al., 2010). Due to the changing nature of culture in the new global context of higher education, of which Sweden is a prime example, equating “culture” and “nation” may be highly problematic. National culture is important, but it is not the only indicator of individual’s learning identity, which is shaped by cultural and ecological characteristics of the learning context.

In the CDIO (Conceive – Design – Implement – Operate) framework, experiential learning is a form of active learning (CDIO Standards 3.0, Standard 8). Active and experiential learning methods are used to directly engage students in taking on roles and responsibilities as well as in thinking and problem-solving activities. In the case study here presented, we implemented Standard 8 through small-group discussions, questions and answers sessions, feedback from students about their progress, concept questions from the instructors (supervisors, customer, examiner, scientific advisor), and demonstration of the product (a working sensor system prototype) at a final workshop, which is also part of the students’ learning assessment (Standard 11). Engaging students in thinking about possible project ideas, taking responsibility for their choices and working on problem-solving increases students’ motivation to achieve the intended learning outcomes and develop habits of lifelong learning. However, this engagement process needs to be accompanied by continuous support from the instructors to avoid that the students may feel lost or overwhelmed. The supportive presence and constant availability of the supervisors and other instructors helps to monitor and review, if necessary, the students’ learning activities, facilitate their progress, and gradually lead them towards organizational independence.

Our course is characterized by the presence of local, national, and international students from different study programs. This diversity ensures a variety of learning styles that influence work dynamics and learning processes in several ways. The multicultural and multidisciplinary environment creates a totally new learning experience that may be used to facilitate, on a hand, the acquisition of knowledge via transformation of experience, and stimulate, on the other hand, adaptation to external conditions. Furthermore, observing the group dynamics and assessing the project outcomes over a medium to long term can help to identify strengths and weaknesses of CDIO implementation in such a learning environment. Matching people with the environment, i.e., understanding the different needs, attitudes, interests, and skills of our students for creating the most suitable and sustainable learning environment, is an effective way to ensure the achievement of the students' learning outcomes (Standard 2).

LEARNING AS A COLLABORATIVE RESPONSIBILITY

When students and teachers come from different cultures, like in our CDIO course, cross-cultural learning situations are naturally developed. Mutual understanding, awareness, and sustained efforts from both teachers and students are required to avoid premature judgements (Hofstede, 1986), misunderstandings, or unfruitful learning situations.

Our cognitive development is determined by the demands of the environment in which we grew up, and it is rooted in the pattern of a society. We become good at doing something if we do something that is important, meaningful, familiar, and repeated frequently. This means that people from different societies process information in different ways, acquire different skills, and consider important different things. Also academic learning is affected by this process, especially when referred to cross-cultural learning. Transparency, open communication, and constructive feedback help the realization of collaborative processes that are beneficial to both students and teachers for increased engagement, learning, and learning retention. Benefits from collaboration may occur at different levels: between students, between teachers, and between teachers and students. Several studies suggest that students and teachers learn more and at a deeper level, are more engaged, and have a higher rate of achievement and retention when working in a collaborative environment rather than alone (Totten et al., 1991; Chiriac, 2014). In addition, a collaborative environment helps students to build or improve personal, interpersonal, and social skills that are important in preparing them for the labor market, where collaboration, teamwork, problem-solving, and other joint missions are key elements of many careers. Collaborative environments allow students to surpass individual limitations, increase reflective and critical thinking, and enhance depth of understanding (Meseke et al., 2010). Positive outcomes from collaborative learning can also be related to teachers' performance in terms of increased commitment and sense of shared responsibility, reduction of isolation, acquisition of new strategies and skills, exchange of information and experiences. Collaboration can be seen as a positive peer-to-peer transfer of knowledge and the occasion to develop social and cooperative skills (Meseke et al., 2010).

In the CDIO framework, the design and implementation of experiences of increasing complexity (Standard 5), in the form of both individual and group assignments, may be offered to help students to reinforce their understanding and integrate prior knowledge and skills for developing new technical disciplinary knowledge and consolidating their hard and soft skills (Standard 2). In our approach, the collaborative environment is considered the foundation of effective and lifelong learning. In other words, we propose an alternative way to apply Standard 1 by considering the framework, and not the product, as the context of learning in which the technical knowledge and several skills are taught. A desired effect of this change of perspective is that the students can feel even more motivated and involved in the learning process because they not only actively participate in the educational processes and contribute to the development of engineering solutions but co-create both processes and solutions together with their instructors. Nevertheless, although most studies warmly applaud the benefits of collaborative learning, there are notable issues to be considered. For example, unprepared peers (e.g., free riders) may be able to pass undeservedly the final examination task or, conversely, may be the cause of weak or dysfunctional groups. Also, problems may arise when group consensus cannot be achieved (Meseke et al., 2010). Besides, there are students who do not feel comfortable to work in group, share information, distribute tasks, and would prefer independent work and individual assignments. How is it, therefore, possible to establish both independent and collaborative routes towards both individual and common objectives? Empowerment of the individual, on a hand, and increasing interdependence between individuals, on the other hand, constitute the new identity of modern Western societies. This simultaneous independence and interdependence is called collaborative individualism (Limerick and Cunnington, 1993). In this context, collaboration and individualism come together into a balance, in the sense of the simultaneous assertion of both. Collaborative individuals are responsible for their own actions while being collaborative and working with others towards common goals. In an engineering learning workspace using the CDIO model, teaching and learning activities aiming at reinforcing both individual and collective skills and competencies at a high cognitive level may use constructive alignment and performative feedback as two powerful tools to help students to develop critical thinking, independence, problem-solving, and creative skills, and to apply them in meaningful ways. Building skills concurrently with disciplinary knowledge and providing opportunities for social learning may help to overcome individual limitations and improve the quality of teaching and student learning (Standard 6).

CASE STUDY

The CDIO course entitled Project Course in Applied Physics, TFYA99 (12 ECTS), is offered to master's students in applied physics, electrical engineering, biomedical engineering, material science and nanotechnology at the Department of Physics, Chemistry and Biology (IFM) at Linköping University, Sweden. The course is designed and developed to meet different backgrounds and interests of multidisciplinary and heterogeneous target groups. During the course, our students develop engineering knowledge, competence, and skills as well as the basics of project management, working as a team in an industry-like environment, using the CDIO concept. The core-part of the course includes the realization of a project in multidisciplinary applied physics that shall lead to the development of a product with large innovation and application possibilities. Projects may be either experiment- or theory-oriented, and application focused. Here, we report on experiment-oriented projects and their impact on our students over the past five years. As an example of successful project work based on the proposed methodology and implementation of CDIO principles in a practical setting, we present the project results of two groups of students who have successfully designed, developed, and tested an innovative sensor system prototype for real-time monitoring of cooking activities using an electric stove (year 2021).

Implementation of the collaborative environment in a practical setting

Our students are highly involved in all phases of their project work. At the start of the course, they form autonomously their groups (typically, four to seven members) and distribute roles and tasks within each group. We only suggest them to be strategic on creating a multidisciplinary team with complementary knowledge, interests, and skills. At least one supervisor is assigned to each group. Active participation within the group and continuous interaction between the groups and with the teaching staff shape the communication styles within the collaborative environment. Introductory lectures and workshops, skills training activities, feedback, and supervision, are offered to support the students' learning and ensure advances in their project work. The CDIO model is used for the entire product lifecycle (Standard 1). To boost active learning (Standard 8) from the beginning, our students are not assigned a project to develop, but encouraged to conceive their own original ideas to pitch at a first decision point meeting with their instructors (examiner, customer, supervisors, scientific advisor). After the approval of the selected idea, they may start working on the design-implement phase. The project ends with the demonstration of a working sensor system prototype in operational environment and the approval of a technical report. Assessment of the students' learning is conducted continuously during the course by ongoing individual as well as group assignments, presentations, skills training and practical activities, technical documentation, students' reflections, peer and self-assessment, observations of students' performance, time management and level of participation at all proposed activities (Standard 11). We observed that inviting students to propose project ideas, to find agreements within their respective groups, and to provide feedback to the other group, is a simple and effective way to enhance teamwork, cooperation, and communication, and engage them directly in their own learning (Standard 6). Offering students the possibility to personalize their learning experience based on their individual and collective interests, skills, and educational backgrounds stimulates their creativity, promote active participation, and increases their interest and motivation towards achieving maximum learning outcomes (Standard 2). The activation of such a virtuous mechanism is important for a course like this where a pass/fail grade could otherwise reduce the students' ambition to achieve the minimum requirements to pass the course.

RESULTS AND DISCUSSION

In this section, we present and discuss the results of student course evaluation and the technical results of two student projects (case study) as evidence of a successful CDIO implementation in a practical setting using an active and experiential learning approach.

Feedback from the students' course evaluation

Figure 1 shows a summary of the student course evaluation during the period 2018-2021. We discarded the results from 2022 because they were deemed statistically inconclusive. The timeframe considered is characterized by iterative improvement of the course based on the feedback received from the students, both oral and written, during group discussions, informal conversations, e-mail communications, and final course evaluations, as well as our personal experience, observations, and feedback shared with and received from the other involved instructors and guest lecturers. Furthermore, this is the period of significant changes in the course syllabus, design, contents, engaging tools, teaching staff, and methodological approach. It is worth noticing that the period considered includes the years of COVID-19 pandemic outbreak that determined highest levels of uncertainty, limited access to laboratory facilities, and significant changes to the learning workspace (Standard 6) and design-implement experiences (Standard 5) during 2020 and 2021. The three questions extracted from the course evaluation refer to the relevance of the teaching and working methods used (Q1), evaluation of the course components (Q2), and overall evaluation and relevance of the course to student's education (Q3) from the student perspective. The results are satisfying in all cases and show an average increase in the mean values from 2018 to 2021. The measures taken during COVID-19 pandemic outbreak to better adapt the teaching and working methods (Q1) as well as the different course components (Q2) to the changing and uncertain situations worked well and produced tangible results, see 2018-2019 before pandemic and 2020-2021 during pandemic. Overall student satisfaction with the course as a positive result of implementing the proposed strategy (Q3) is demonstrated by high rating throughout the period considered and a 20% net increase from 4.0/5.0 in 2018 to 5.0/5.0, in 2021. The positive trends recorded over the years of increasing implementation of engagement tools indicate a general preference for this new approach compared to previously more defined projects.

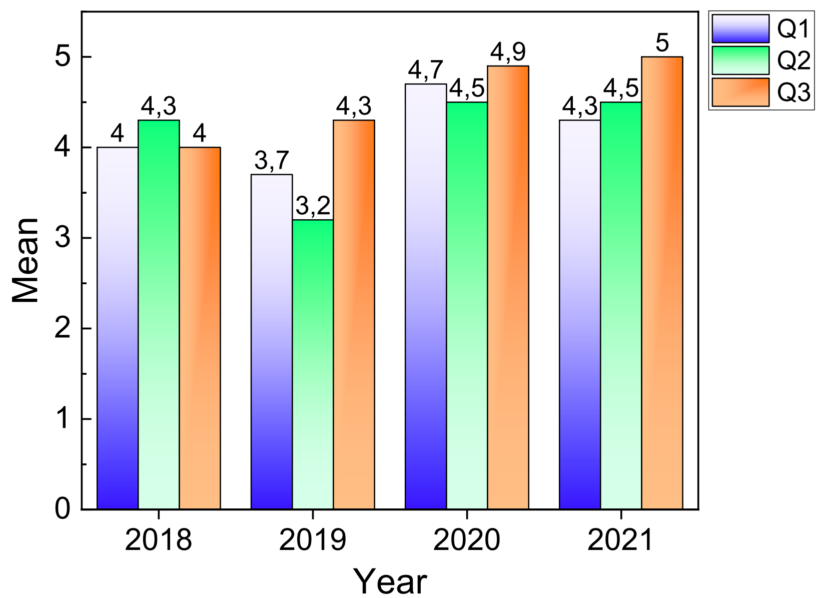


Figure 1. Students' answers to three of the questions contained in the course evaluation during 2018-2021.

These very positive results are clear proof that the improvements introduced in the course work well and are well perceived by the students.

Conceive-Design-Implement-Operate a working system

Our CDIO course is a project-based course that uses an experimental and experiential approach to facilitate and stimulate students' active learning through multiple engaging experiences (cfr. Kolb, 1984, and CDIO Standard 8). In 2021, two groups of students designed, developed, and tested an innovative sensor system prototype for smart monitoring of cooking fumes, heat, and steam, and automated control of a stove hood. Each group consisted of six students. By use of a budget time of 240 hours over a period of about four months (September-December), the two groups of students demonstrated that, depending on the measured concentration, the system can switch the fan on/off and regulate its speed with the effect of suppressing pollutants that are released while preparing food, and reducing power consumption.

Both prototypes included three main subsystems, even if designed and implemented differently: (1) a sensor unit for monitoring typical indoor air pollutants emitted during cooking activities, namely particulate matter (PM), total volatile organic compounds (TVOC), formaldehyde (CH_2O), carbon dioxide (CO_2), plus temperature (T) and relative humidity (RH); (2) a control unit for signal reception, processing, and transmission to the hood; and (3) and a cooking unit containing an electric stove and hood for experiments. Best-in-class commercial sensors for measurement of the mentioned pollutants and environmental parameters were selected based on certain requirement specifications. In the case of prototype #1 (Figure 2), the housings for the electronics and sensors were manufactured using 3D printing technology, whereas in the case of prototype #2 (Figure 3), the chamber hosting all hardware components of the system was realized using recycled waste materials as a sustainable choice.

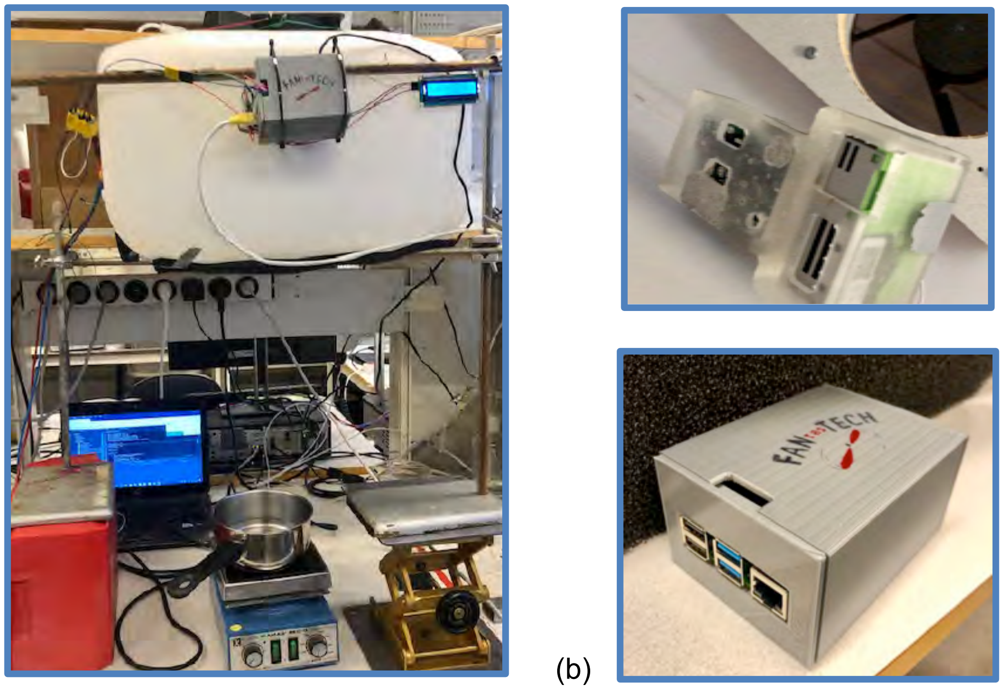
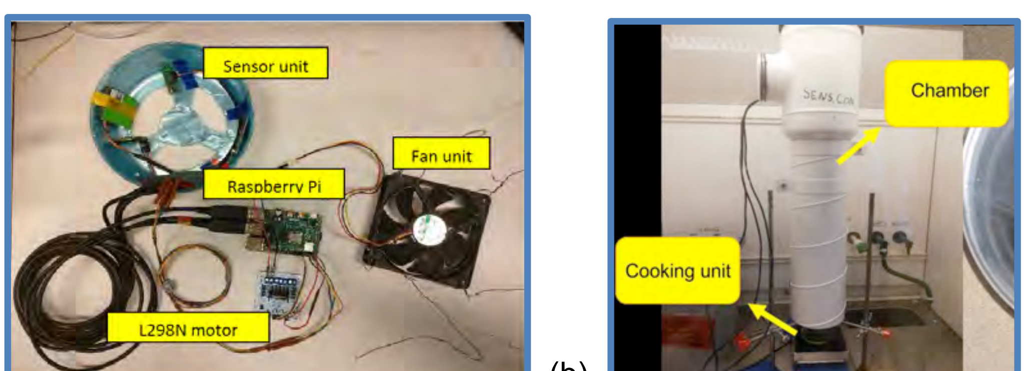

(a) (b)

Figure 2. (a) Sensor system prototype #1 by FANtasTECH Team; (b) Containers for the sensors and control systems realized using 3D-printing technology.



(a) (b)

Figure 3. (a) Sensor system prototype #2 by SENS.CON Team; (b) Cooking unit and chamber hosting all hardware components of the system.

Experiments were performed in both laboratory and home environments. Gas and particulate emissions from common cooking activities, such as boiling water and frying rapeseed oil with

or without bacon, onion, and eggs, were measured over time, and the efficiency of grease filters was evaluated.
During the process of boiling water, FANtasTECH prototype #1 measured an increase of RH as well as of CO_2 concentration after about 180 s from the start of activity. The temperature increased steadily either with or without the grease filter. The PM concentration remained around zero until the water reached the boiling point, then some PM peaks were measured. Temperature and RH were used as indicators to turn the fan on when boiling water. During the process of frying rapeseed oil, PM increased after about 160 s from the start of activity. Also the temperature increased with time, as to be expected. Since the PM concentration increased significantly as the oil began to heat up, the fan was programmed to start when the PM concentration level increased by 500% from its mean value. RH percent and CO_2 concentration varied significantly during the measurement, with no clear trend or pattern, and were therefore excluded as relevant parameters.

During the process of frying bacon (Figure 4), SENS.CON prototype #2 measured a significant decrease in the TVOC index (a.u.) from 450 to 120 when the kitchen fan was switched on. Based on the conducted experiments, PM and TVOC were demonstrated as main contributors to indoor air pollution when heating rapeseed oil. An increase of CH_2O concentration was observed when frying bacon, onion, and eggs with rapeseed oil. Also in this case, the CO_2 sensor showed no correlation to the cooking process when an electric stove is used.

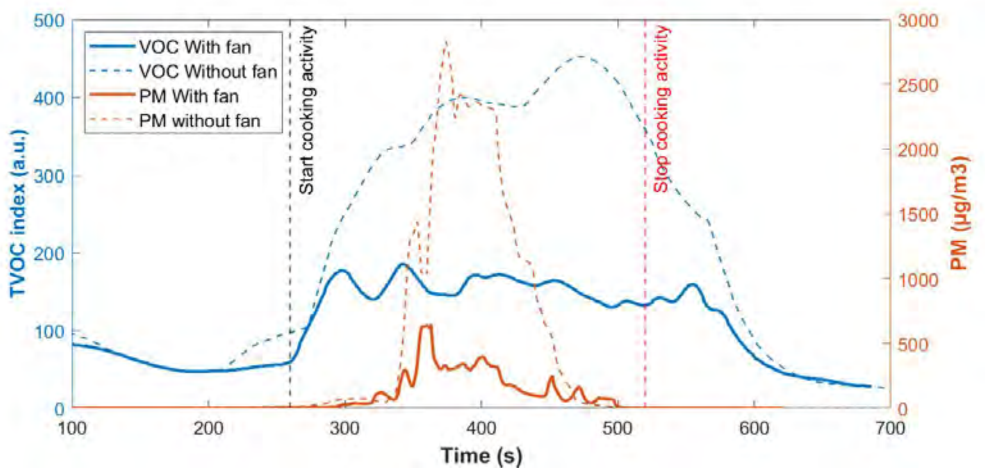


Figure 4. Cooking activity: frying bacon with (straight line) or without (dotted line) the fan activated. Emissions of TVOC (blue) and PM (red).

In summary, the results obtained by both groups are scientifically robust, relevant, and original. As proof of this, the scientific findings were presented as an oral contribution to a well-established international conference focusing on the latest scientific advances and ongoing research in the field of indoor air quality (Domènech-Gil et al., 2022). Furthermore, the student projects received attention from our university press for their novelty and scientific relevance, innovation aspects, and good example of a collaborative learning environment that can produce results beyond expectations and can therefore be a source of inspiration and motivation for others as well (Planthaber, 2021).

CONCLUSIONS

Multidisciplinary and open-ended projects can be challenging to design and implement, but also a great tool for active and experience-based learning. The different components contained in this course allow our students to design, develop, and test successfully, in about four months, their unique working sensor system prototype with potential interest for the market. The high-quality results from the case study clearly demonstrate that the students achieved technical disciplinary knowledge at an adequate level (Standard 2). The opportunity to conceive-design-implement-operate a prototypal product, co-create the process, combine multidisciplinary knowledge, and develop both technical and personal and interpersonal skills not only offers students to acquire solid knowledge and understanding on which they can build the foundation for their future, but it is also beneficial for other co-curricular activities, such as undergraduate research projects, thesis works, and internships (Standard 5). The emphasis on building a working system containing elements of applied physics combined with sensor technologies, electronics, programming, 3D-printing, and sustainability, getting inspired from daily life experiences, and envisioning possible applications in real-world contexts provides students with the opportunity to make connections between the technical content they are learning, the usefulness for their future studies and careers, and the impact on societal needs.

Over the years, the TFYA99 course has been proven to cater for diverse backgrounds and interests of international, multicultural, and multidisciplinary target groups. In the past five years, this project has received an increasing overall course evaluation from 4.0/5.0 to 5.0/5.0.
Based on the results presented, we can conclude that working in a collaborative environment that fosters, among other factors, mutual help, trust, open communication, information exchange, feedback, peer and self-assessment is beneficial to student learning outcomes and is clearly reflected in student satisfaction. This type of CDIO implementation is not only beneficial to our students. It is a useful active and experiential learning process for instructors as well. Well designed and interconnected course components, cooperative and well-functioning teamwork, adequate work environments, and dedicated mentoring accompaniment are reflected in the high level of motivation, interest, creativity, and commitment of both the teachers and the students. Success lies in the process.

Designing project-based courses and experiments related to an everyday life situation like this enables effective and lasting learning. This type of educational approach allows engineering students not only to strengthen and apply both theoretical and practical knowledge, but also to directly transfer the findings from their measurements to their personal environment, with a direct impact on their attitudes, behaviors, sustainable choices, and career paths.

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MAXIMISING ACADEMIC AND SOCIAL OUTCOMES

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ABSTRACT

The MASOEE project brings together engineering faculties in the EUniWell alliance to share best practices for teaching transversal skills so that engineers contribute to societal well-being. The study combines the expertise of several engineering faculties at European universities. It focuses on sharing and developing expertise to improve the social outcomes of engineering students. Namely, researchers examine the similarities and differences between partners regarding their student bodies, teaching, programme structures, and institutions' culture. Moreover, the work also explores how transversal skills are taught, what student attitudes are in terms of learning these skills, and how educators can better teach them.

The research design includes several activities across four work packages (WPs). To ensure that partners use the same skill descriptions, we use well-established organizations' existing definitions. WP1 strives to identify best practices within EUniWell based on the 15 entrepreneurial competencies defined in EU EntreComp Framework. WP2 targets engineering students' ability to solve complex challenges, communication, and networking skills defined in the "21st century skills" by the World Economic Forum. WP3 investigates the engineering schools' capacity to train engineering students in sustainable competence, forming responsible engineers capable of developing sustainable solutions using the skills defined by the EU GreenComp. WP4 supports the other packages with engineering education research, specifically data collection and analysis, knowledge forming, and evaluation. The project runs from August 2022 until September 2023.

The MASOEE project partners gather knowledge within their organisations through joint surveys and focus groups and collectively identify and share best practices. The engineering identity, taught as transversal skills by participating partners, can evolve from a traditional technologist identity along three paths: the self-made engineer, the progressive technologist,

and the responsible engineer. By sharing best practices for teaching these skills, we believe we will better understand what the future engineer - who integrates all three identities – will be.

KEYWORDS

Social competencies, self-made engineer, 21 century skills, Responsible engineer, Entrepreneurship, Sustainability competence. CDIO standards: 3, 5, 7, 8, 9, 10, 11

INTRODUCTION

The EUniWell alliance mission is to resolve the paradox of Europeans' relative levels of prosperity against the global challenges in society they face: health, environment, political instability, and defence. Maximising Academic and Social Outcomes in Engineering Education (MASOEE) interprets this contradiction for the engineering profession as how to best teach the non-technical skills to ensure engineers make their utmost contributions to societal wellbeing. Our strategy is to bring together the expertise of Birmingham, Florence, Linnaeus, and Nantes engineering faculties. These EUniWell engineering schools will share and develop expertise to improve the social outcomes of engineering students (Figure 1).

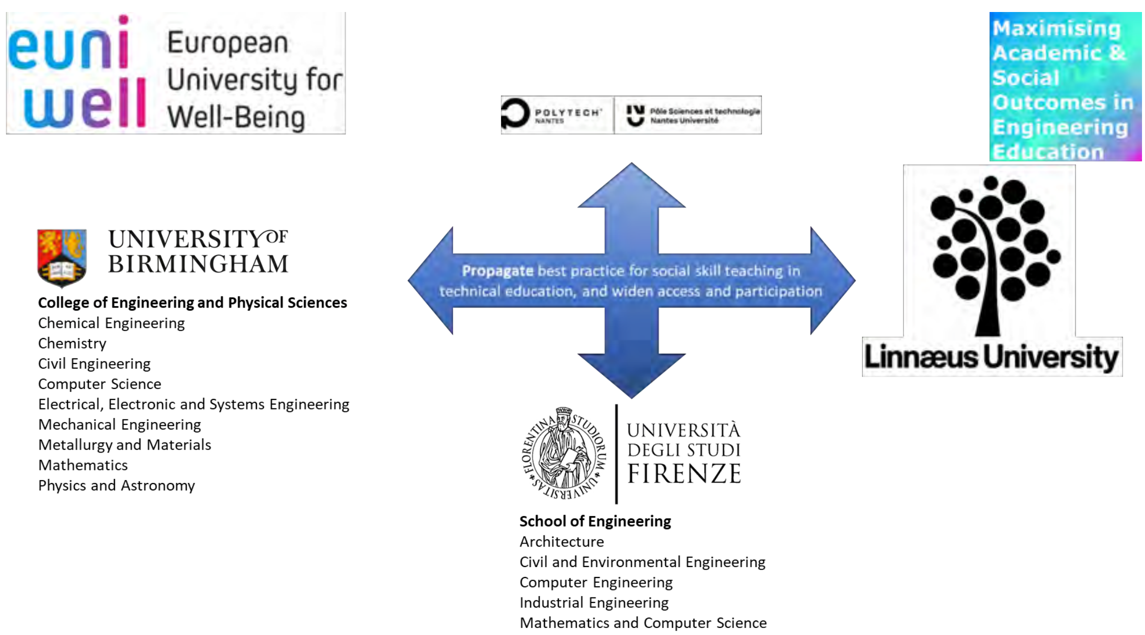

Figure 1. MASOEE partners

Figure 2 shows an overview of the project. Several activities are planned with outputs. Three skills sets are defined, and each partner assumes responsibility one of them to run workshops and data collection activities (right box). The school of education at Birmingham will advise the format for data collection (left box) so that research questions can be answered. The activities will result in a set of case studies which consider the adoption of best practice across institutions (centre boxes). The following sections describe each activity and provide some context.

MAXIMISING ACADEMIC AND SOCIAL OUTCOMES

This is the core of the project. An academic outcome for engineering is defined as the technical skills that are acquired by students in their studies. These include the basics of science and mathematics, design, and analysis skills, as well as the use of engineering tools and methods. In contrast, non-technical skills are referred to as “social competences” where outcomes are defined by:

1. How partners teach non-technical/social competencies in the context of a technical education.

2. How partners widen participation of disadvantaged groups and narrow attainment gaps.

How do partners teach non-technical/social competencies in the context of a technical education?

Engineers solve problems by applying scientific knowledge and principles. Consequently, engineering culture is considered distinct from other disciplines (Van den Bogaard, 2021) and purposely depoliticized (Cech E., 2013) so that it is best for engineers to practice independently of public affairs and/or leave such issues to other professionals such as social scientists and politicians.

Figure 2. MASOEE activities

This narrow focus on technical competence leads to students acquiring an engineering identity that can be considered a “traditional technologist” (Berge, 2019). Contemporary engineering education in most faculties has shifted away from this identity towards 3 new identities; each of which corresponds to a skill set defined in the MASOEE project (Table 1). These emerging identities for the engineer are: the “self-made engineer”, the “contemporary technologist”, and the “responsible engineer”.

The “self-made engineer” can be considered one who develops a meritocratic and individualistic ideology through their study primarily to improve their employability in the job market. This is partially promoted through learning enterprise, innovation, and creativity skills. This orientation is sometimes at the expense of beliefs in public welfare including professional and ethical responsibilities, and the consequences of technologies (Cech E. A., 2014).

Table 1. Engineering identities [Berge,2019] mapped to MASOEE skills

Engineering identity as defined by (Berge, 2019)	**MASOEE skills**
Traditional technologist (status-quo)	Science and maths, design, analysis, engineering tools and methods.
Self-made engineer (neoliberal trends)	WP1 Entrepreneurship: Innovation, enterprise & creativity.
Contemporary technologist (progressive trends)	WP2 Solving complex challenges: Communication & networking.
Responsible engineer (sustainability trends)	WP3: Sustainability competence: Technical, social & environment responsibility.

The “contemporary technologist” is someone who retains the importance of technology skills, yet acknowledges the need to acquire the generic, softer professional skills such as report writing, project management and team skills which are easy to operationalise. Like the “self-made engineer”, the motivation of the student to adopt this identity is typically improved employability, which serves the modern neoliberal agenda of universities where competition and value of money are key foci (Berg, 2016). A key resistance to teaching these professional skills is the ability of engineering academics to teach them due to lack of capacity; capability, motivation, and opportunity.

The “responsible engineer” encourages a morally responsible stance to be taken where technical skills serve the greater good of society and the environment. The chief focus is on ethical behaviour with a greater consideration of how technology is developed and for what purpose. Typically, the responsible engineer follows the sustainability agenda for social wellbeing, climate change, energy, and food security.

To summarise, modern engineering curriculum has moved from educating the student to the professional identity as the “traditional technologist” towards the “self-made engineer”, “contemporary technologist”, and “responsible engineer”. Each of these new identities is valuable and not mutually exclusive. Therefore, understanding how each of these three identities and their underlying skills sets are taught by MASOEE partners might reveal key insights into how the engineering identity is formed.

The hidden curriculum

Fundamentally engineering is about applying scientific methods and knowledge to create new products, processes, and services (Lucas, 2014). This encourages engineers to maintain a mindful separation of “technical” and “social” competence – an ideology referred to as “social-technical” dualism (Faulkner, 2007). This dualism can be reinforced by how curricula is designed and delivered. Appreciably, separate learning units for skills, delivered by non-engineering experts creates an idea of the hidden curriculum; non-technical competencies are duly taught and learned, but not widely thought of as an engineer’s problem, not fully integrated into day-to-day engineering habits, or practiced post-study. This phenomenon is known as “the hidden curriculum” (Tormey, 2015).

How partners widen participation of disadvantaged groups and narrow attainment gaps

The global marketplace for higher education and its neoliberal trends, where students are customers and higher education produces employment-ready graduates, leads to social outcomes in education being considered chiefly through graduate destinations and earning potential (Berg, 2016). Since engineering is a relatively well-paid profession, the ultimate social outcomes of studying engineering and then entering its profession for the individual can be considered net positive. Thus, engineering education can be a force for social mobility by widening access for disadvantaged students, as long as the learning environment delivers an equitable education and closes any attainment gaps between disadvantaged groups and the mainstream cohorts.

MASOEE partners have different definitions for what is considered a disadvantaged student, so what these differences are and how they are dealt with will be a valuable knowledge exchange.

WORK PACKAGES (WP1-3)

Professional skills inventories are well understood and described in the literature. The MASOEE project will involve knowledge exchange of how these skills are embedded in programmes and identify best practice. So that all partners share a common definition for discussing the skills sets, the project will draw on existing skill inventories and taxonomies: for WP1 EU EntreComp (Bacigalupo, 2016), For WP2 WEF 21st Century Skills (World Economic Forum., 2016), and for WP3 EU GreenComp. MASOEE partners will identify the parts of their curricula where similar learning outcomes reside in the curriculum mapping exercise. A final work package, WP4, considers research design and analysis.

WP1 Entrepreneurship (Innovation, enterprise, and creativity)

To create "self-made engineers", the skills needed including are described in the EU EntreComp Framework (Bacigalupo, 2016) – see Figure 3.

Figure 3 Visualisation of EU Entrecomp (Bacigalupo, 2016)

There are 15 competences are equally split equally across 3 areas – "Ideas & Opportunities"; "Resources" and "Into Action". The framework adds further value by providing a progression model for skills and provides 442 related learning outcomes for consideration/inspiration in defining modules and programmes.

WP2 Solving complex challenges (Communications and networking)

To create "broad technologists", Communications and networking involve a set of skills around professional capabilities such as project management, teamwork, and written communication. These are best captured by the "21st century skills" by the World Economic Foundation (World Economic Forum., 2016) (Figure 4). This splits the skills into 3 categories: foundational literacies, competencies, and character qualities.

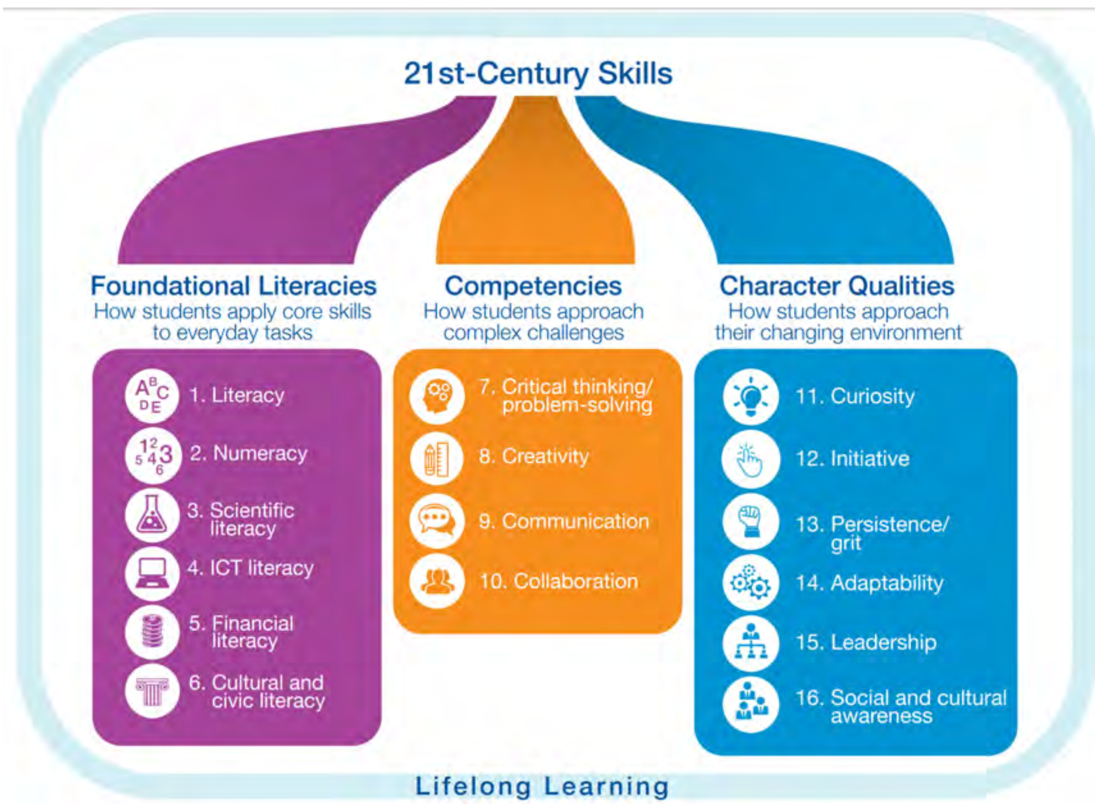

Figure 4 Visualisation of 21st Century Skills (World Economic Forum., 2016)

WP3 Sustainability competence: Social, environment, and technical responsibility

To create "Responsible engineers", the EU GreenComp framework serves as a useful model to capture the skills (Bianchi, 2022) – see Figure 5. This considers sustainability across 4 areas: embodying sustainability values, embracing complexity in sustainability, envisioning sustainable futures, and acting for sustainability. In each area there are several skills.

Figure 5 Visualisation of EU GreenComp from [Bianchi (2022)]

Sustainability is considered a transformative technology, that together with digitalization creates a framework for future products and markets (Guandalini, 2022). This development increases the need of knowledge for the engineer to be able to handle and master the skills and key competences needed (Redman & Wiek, 2021). The engineer will need a broader toolbox of and be able to connect different fields and competences (Venn et al, 2022). The student should during the education get the opportunity to train the key competences for sustainable development by learning to solve complex challenges (Unesco, 2020).

Systemic adoption across partners

MASOEE partners will share best practice through sharing case studies. Moreover, to facilitate integration of new practice into their institutions, the case studies will be structured drawing on the literature of diffusion or innovations framework – notably the propagation paradigm (Froyd, 2017) where the key object is to maximise the efficacy and the fit to the partner to allow for meaningful adoption (Figure 6). The characteristics of a propagation paradigm include:

- The focus being fit rather than evidence of efficacy. This requires dialogue with partners for how to adapt an innovation at a partner.
- The innovations should be characterised by usability to provide generalisation to other settings, rather than strong data.
- Partner interactions through case study presentations ought to support adoption rather than raise awareness.
- The different instructional systems, e.g., Canvas, Moodle, must be considered as part of the case study so that technical frictions can be reduced.

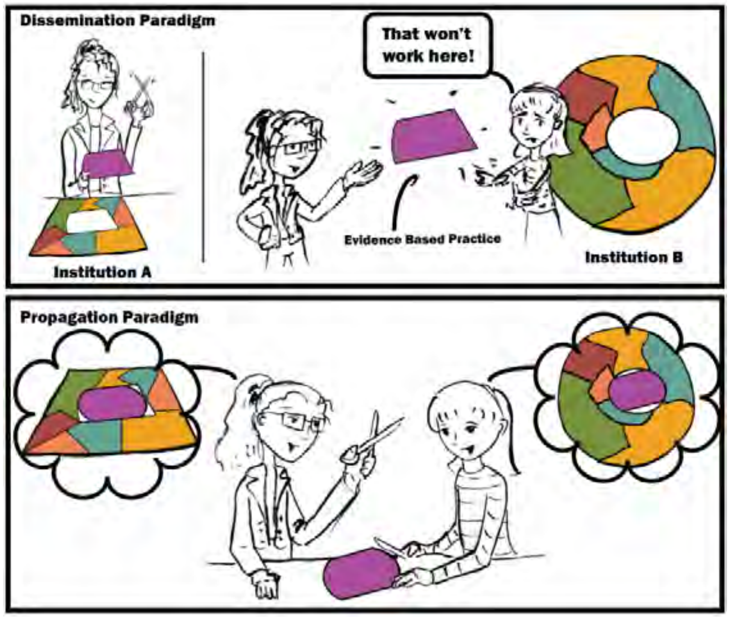

Figure 7 Visualisation of the propagation paradigm and differences with deamination paradigm (Froyd, 2017)

Engineering education research (WP4)

The Engineering research activity will guide the data collection in the study so that it can help answer some key research questions for the project. The three research questions are:

- RQ1: What are the similarities and differences between engineering partners, their student bodies, teaching, programme structures, and institution culture?
- RQ2: How are the skills currently taught and embedded in programmes? What are student attitudes to learning these? How do we define and measure social outcomes?
- RQ3: Which new approaches can we employ to better teach these skills that deliver better social and academic outcomes?
- To answer these questions, the following data is captured:
  - Curriculum mappings – where skills are taught in the partners.
  - Student questionnaire on attitudes to learning non-technical skills.
  - Staff questionnaire on attitudes to teaching non-technical skills.
  - Semi-structured interview and focus group protocol on student attitudes to partner teachings.
  - Semi-structured interview protocol on staff attitudes to other partner teachings.

Once the data is captured, responses will be transcribed, translated, and coded before analysis techniques employed following a mixed-methods approach.

- For analysis of attitudes: Exploratory factor analysis (Fabrigar, 2011), Self-determination theory (Deci, 2012):

- To compare differences between partners: Activity theory (Nussbaumer, 2012), Legitimation code theory (Maton, 2015).

Mixed methods

The MASOEE project aims are to examine the similarities and differences between institutions in terms of student bodies, teaching, programme structures, and institutional culture. However, we also want to explore how skills were taught, what student attitudes were in terms of learning these skills, and how we can better teach them. Whilst it is possible to gather some of this data within a quantitative manner, exploring student attitudes needs a more qualitative approach, leading to the decision to adopt a mixed method research design.

Johnson and Onwuegbuzie (2004) argue that when comparing a single method research approach with a mixed method one, it is the diverse nature of mixed methods that results in "superior research" (Johnson and Onwuegbuzie, 2004, p14). They further argue that mixed methods allow researchers to develop a greater understanding of the strengths and weaknesses of both singular paradigms, which then allows the research team to develop strategies by using and combining methods that would complement each other and ultimately be of most benefit to their study (Johnson and Turner, 2003; Johnson and Onwuegbuzie, 2004).

It is important to establish how each component within a mixed method project interacts (Denscombe, 2017), for example, does a component create a more complete picture or does one component guide another component. To help understand how this mixed method research has been structured, the research questions were broken down into each method used to help answer it. The different methods used will be: documentation analysis, surveys, followed by interviews an focus groups to reflect different aspects (Figure 7).

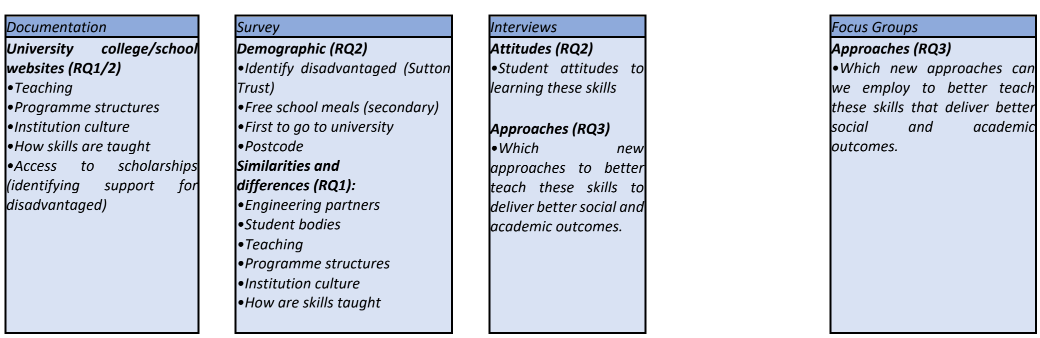

Figure 7 Overview of research questions and methods used to answer them

Reflecting on how each component relates to the others (Denscombe, 2017), the documentation and survey aspects are both designed to obtain an overview of current practices, demographics, and similarities and differences. The interviews and focus groups are designed to explore attitudes and approaches and will build on information found within the documentation and survey phase. There is a mixture of qualitative and quantitative approaches required.

CONCLUSION AND DISCUSSION

EUR-ACE accreditation standards, CDIO, and a globalised engineering educator profession cultivate the standardisation of degree programmes across the European continent. Despite this, engineering faculties have different cultures and contexts in which they have developed their programmes to teach engineering skills to best serve their employment markets and optimised to suit their unique student populations. All partners have practises for students to learn these soft skills, however different approaches, and methods to train them. The first part of the project has compared program structures and teaching cultures, finding both similarities and differences. By meeting in developing workshops, a creative learning process has been started and the questions are brought into focus, but what is the common core of the different education systems? The MASOEE project aims to maximising both the academic and social outcomes in engineering education through systematic sharing of knowledge and expertise across borders to discover differences in approaches to teaching skills and how they might be adapted in new contexts.

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BIOGRAPHICAL INFORMATION

Neil Cooke has vast experience from research and teaching activities covering systems and data engineering, multimodal physiological signal processing, artificial intelligence, affective computing, visualisation and virtual reality, medical informatics; educational technologies and engineering education. His work spans several industrial domains including defence training and simulation; medical, telecommunications infrastructure and education. He has designed, developed and delivered 100+ credits of different innovative teaching materials at all degree levels, supervised upwards of 70 project students, contributed to higher education teacher training, conducts Engineering education research, lead designing and implementing laboratory curriculum change initiatives across STEM faculties, and has extensive international student recruitment and outreach experience. He has co-authored 27 publications in peer review conferences and journals. He served on the board of directors for the European Society of Engineering Education (SEFI) between 2017 and 2022, and currently chairs their special interest group on engineering skills, as well as co-writing, producing and presenting their “European Engineering Educators” podcast.

Jörgen Forss focus areas are environment and resource utilization in both teaching on engineering programs, interdisciplinary environment, and sustainable development courses. He strives to put the student and science at the centre through different pedagogies e.g. flipped classroom. He also supervises degree workers in water, materials, and resource matters. His research is connected to water, processes, and purification, preferably with connections to energy and environmental applications. Some previous projects have had connections to developing countries and how concepts around purification can be built with small resources. Projects his been involved in: purification of textile dyes, identification of fungi and bacterial composition in water purification filters, foam formation in septic tanks, filter purification techniques, algae as carbon dioxide filters for biogas, water use in apartment buildings.

Sarah Chung qualified as a primary school teacher, specialising in English, in 2004. She has worked throughout Key Stages 1 & 2 as both a class-based teacher and supply. After becoming a governing at her children's school in 2015 she developed an interest in educational leadership and decided to pursue an MA in School Improvement and Educational Leadership at the University of Birmingham. The MA supported her development as a governor and her later roles as Chair and Vice-Chair of governing bodies in the West Midlands.
In 2018 she was awarded a CoSS Scholarship and began her PhD journey within the School of Education, exploring the role of governor training. During her second year (2019/20) she became a Westmere Scholar, supporting PGRs across the University of Birmingham. In her third year, she has taken on the role of General Co-Editor of Ad Alta: The Birmingham Journal of Literature. Now in her fifth year she's based in the School of Education.

Jesper Andersson is a Professor in Computer Science at Linnaeus University. He received his PhD. in Computer Science from the Department of Computer and Information Science at Linköping University in 2007. His research focuses mainly on Software Engineering techniques and methodologies supporting the development of smarter systems. He has published several papers in distinguished journals and conferences in Self-adaptive Software Systems, Software Reuse, and Software Ecosystems. He has also served in organization and program committees för several international conferences, symposiums, and workshops.

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INTEGRATING SUSTAINABILITY THINKING IN INFORMATION SYSTEMS – EXPERIENCES FROM AN ENTERPRISE ARCHITECTURE COURSE

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ABSTRACT

The rapid changes in the environment and our societies have raised the importance of incorporating Sustainability Thinking in all our courses. However, this is more challenging for some subject areas than others. Although Sustainability Thinking has long been a tradition in some of the engineering subjects, this is a far greater challenge for students of more abstract subjects such as Computer Science and Information Systems. The challenges in understanding sustainability are not only for our students; it is also hard for teachers to conceive how Information Systems could impact the UN SDGs in positive and negative ways. The question that many Information Systems teachers are asking is how we could incorporate Sustainability Thinking into the courses. This paper is aimed at sharing experiences from an Information Systems course on Enterprise Architecture for Enterprise Innovation, where we have integrated the ideas of Sustainability Thinking and sustainable innovation in enterprises. We have taken a step-by-step approach to introduce the basic ideas of Sustainability Thinking and to integrate them into the learning activities. The main research question addressed in this paper is how to integrate Sustainability Thinking into a course on Enterprise Architecture and Enterprise Innovation. The approach that we have taken is to integrate Sustainability Thinking as a part of the contents and activities in the course rather than enhance the syllabus by adding sustainability related content as an additional subject. The paper describes the course and how Sustainability Thinking has been integrated into the curriculum and the learning activities. An assessment of students' awareness of sustainability and their attitudes to applying the ideas in their future work in designing IS are also presented.

KEYWORDS

Sustainability Thinking; CDIO Optional Standard 1; Enterprise Architecture; Information Systems; Education.

INTRODUCTION

Sustainability has become an increasingly important aspect of modern life, as we strive to balance economic growth while protecting the natural environment and our societies. The need to understand sustainability and to raise awareness about Sustainability Thinking has become an essential part of education and research, independent of the study discipline, e.g. sustainable value creation and addressing real world challenges now have a place in university strategies

(Norwegian University of Science and Education (NTNU), 2018). Information Systems (IS) and Information and Communication Technology (ICT) have been identified as one of the enablers of sustainable value creation as they play a central role in many aspects of modern life (Jeffrey D. Sachs et al.). The need to raise awareness of sustainability of the ICT applications that we develop to achieve sustainability by ICT, or ICT as an enabler of sustainability, has been identified as a need to be addressed in educating ICT solution developers (Pattinson, 2017). One of the reasons for the challenges in managing the sustainability of digital information and IS is due to a lack understanding of sustainability in all the stages of the lifecycle of such systems. It has been argued that this is due to a lack of focus on this in Information Science research (Chowdhury, 2013) and that the different aspects of sustainability (social, economic and environmental) and their implications must be introduced to the designers of such systems; our students would play this role in the future. Yet, there are few studies that describe the integration of sustainability into their curricula in IS courses. Moreover, there are studies that identify the lack of focus on sustainability and environmental issues in IS curricula (Rubio et al., 2019).

Designers of ICT solutions and requirements engineers lack adequate understanding of sustainability to make it a priority in their solutions (Chitchyan et al., 2016). Several IS courses, such as the one described in this paper, focus on the requirements and design phases of ICT solutions, where an understanding of sustainability and the implications of the design are of utmost importance (Becker et al., 2016; Penzenstadler et al., 2014). The CDIO 3.0 syllabus has been motivated to include external drivers, such as sustainable development, in the CDIO standards (Malmqvist et al., 2022). As such, the need to integrate sustainable development into the curriculum has been defined as CDIO Optional Standard 1 (Malmqvist et al., 2017; Malmqvist et al., 2020).

Incorporating Sustainability Thinking into IS studies, and particularly subjects such as Enterprise Architecture that reside at the intersection of business and ICT strategies for an enterprise, can have positive impacts on the financial bottom line of organisations and could help enterprises to attract and retain socially responsible customers and employees. Therefore, as students of IS, it is important to be aware of the importance of sustainability and to understand the various ways in which it can be incorporated into technology solutions.

Although Sustainability Thinking has long been a tradition in some of the engineering subjects such as production systems where the products are tangible and their lifecycles are easier to follow, this is a far greater challenge for students of more abstract subjects such as Computer Science and IS. A survey among 3rd -5th year university students studying Enterprise Architecture for Enterprise Innovation (the course reported in this paper) showed that only 3.3% of the students have had courses that relate sustainability to ICT, enterprises and innovation, and 13.3% of them have had courses related to sustainability or that incorporated sustainability in the study program. The challenges in understanding sustainability and the UN SDGs are not only a challenge for our students; it is also hard for teachers to conceive how information systems could impact the UN SDGs in positive and negative ways. Thus, it has been neglected for far too long and it is now time to act upon this important and urgent issue so that our future designers of IS make well-informed and wise choices, taking into account the well-being of the people, our societies and the environment. The question that many ICT teachers are asking is how we could incorporate Sustainability Thinking into our courses. We believe that currently there is no perfect blueprint for this, or a best practice, and therefore sharing experiences and learning from one another may be one of the best ways forward in this endeavour. This paper is aimed at sharing experiences from a course on Enterprise Architecture for Enterprise Innovation, where we have incorporated the ideas of Sustainability Thinking and sustainable innovation in enterprises since 2020. We have taken a step-by-step approach to introduce the basic ideas and to incorporate them into the learning outcomes and learning activities. Our overall approach has been the systematic integration of sustainability into the existing syllabus rather than introducing a new topic on sustainability. We started by identifying the topic in the syllabus where it was easiest to integrate sustainability ideas and continued by integrating it into a few more topics in the curriculum. Furthermore, we have included groupwork and students' reflections as a part of the learning activities.

The main research question addressed in this paper is how to integrate Sustainability Thinking into an IS course on Enterprise Architecture and Enterprise Innovation. The approach that we have taken is to integrate Sustainability Thinking as a part of the contents and activities in the course rather than enhance the syllabus by adding sustainability related contents as an additional subject. The paper describes how Sustainability Thinking has been integrated into the current course curriculum and students' responses to a survey which asks them about their awareness and attitudes towards sustainability in enterprise innovations and design of IS solutions. Thus, the main contribution of this paper is the experience and lessons learned from the endeavour, which may be beneficial for teachers and researchers in the field of IS.

The rest of this paper is organised as follows: Section 2 provides a brief overview of Sustainability Thinking in higher education and IS courses; Section 3 describes the method; Section 4 describes the course and how CDIO is implemented in the course; Section 5 describes how Sustainability Thinking is integrated in the course; Section 6 shows the results from an evaluation; Section 7 discusses the limitations of the study and Section 8 concludes the paper.

SUSTAINABILITY THINKING IN HIGHER EDUCATION

Sustainability Thinking has been identified as a skill that is a requirement for our future engineers (DAMVAD Analytics, 2022). It can be described as the "capacity to engage effectively with social, environmental and economic change and challenges in the contemporary world" (Le Trobe University, 2015). Systems Thinking and Responsible Futures are two main ideas in Sustainability Thinking. Systems Thinking involves considering the complex interactions between different factors, and Responsible Futures, involves reflecting upon the effects of one's own actions and decisions. This involves understanding the complex interactions between nature, economy, society and our culture and being able to reflect on our obligations to future generations. Successful integration of Sustainability Thinking depends on the approach to engineering education. A learner-centred approach, where the students are able to contribute with ideas, learning material and actively participate in the learning activities is considered as important for enhancing Sustainability Thinking among university students (Huntzinger et al., 2007). Interaction with teachers and other actors have also been identified as a means of integrating sustainable development into educational programs (Holmberg et al., 2008). One such approach is using debate as a means of improving students' understanding of sustainability and critical thinking skills (Alaswad & Junaid, 2022). Groupwork (Newstead & Reinwald, 2022) and empowerment of students as a part of their learning process have also been identified as means to enable the development of their critical thinking skills (Cheah et al., 2022), which is also an important skill in Sustainability Thinking (Minott et al., 2019; Straková & Cimermanová, 2018).

The need for integrating Sustainability Thinking into Software Engineering education has received attention in recent years (Becker et al., 2015), and examples of integrating it into teaching programs have been reported in the literature, e.g. (Penzenstadler et al., 2018). Proposals for incorporating sustainability and the relationship to ICT in Computer Science and IS curricula have been addressed in the literature. Some of these include topics such as the key concepts of sustainability, Systems Thinking, ICT and Ethics and Green IT (Özkan & Mishra, 2015). Guidelines for incorporating sustainability in existing IT courses, based on the ACM/IEEE guidelines 2017 for Information Technology have been proposed in (Mishra & Mishra, 2020).

METHOD

This paper reports the experiences from a course on Enterprise Architecture for Enterprise Innovation (*TDT4252 - Enterprise Architecture for Enterprise Innovation*, 2022), where Sustainability Thinking has been integrated into the curriculum. It is a Masters level IS course module offered by the Department of Computer Science, which is taken by students from several faculties including Engineering, Industrial Economics and Technology Management. The overall research approach that has been used for the course is Action Research (Water-Adams, 2006), where a cycle of planning, action and reflection is considered, to improve the course every year, by systematically inquiring and analysing qualitative data that can stimulate self-reflection, critiquing and improving the practice of teachers (McCutcheon & Jung, 1990). As a part of this improvement cycle, the course is also upgraded to meet the emerging needs of students as well as internal and external drivers, such as the global need to meet sustainability requirements and the university's strategy (Norwegian University of Science and Education (NTNU), 2018). As such, we have taken a step-by step approach to integrating Sustainability Thinking into our course. Integration of sustainability into the existing syllabus was prioritised rather than enhancing the syllabus with new content. The first step was to identify where it was easiest to integrate the ideas into the syllabus. Then, we identified where the students could apply the ideas of sustainability best in their learning activities and enhanced the learning activities to learn about sustainability. We are currently working on integrating the ideas in the entire course.

For the specific study described in this paper, the main data collection method was a survey given to the students at the end of the course. The survey was aimed at obtaining feedback from the students. Students were given some statements related to Sustainability Thinking and asked to indicate their level of agreement to the statement, where the levels were Strongly agree, Agree, Neither agree nor disagree, Disagree and Strongly disagree. The survey was administered using a university approved online survey tool. Respondents consent was obtained and no privacy data was collected.

COURSE DESIGN

The learning outcomes of the course include theoretical insights into business and Enterprise Modelling, service innovation, methods for analysing organisational situations and modelling them, and to develop competences on the broader technological, business and social context related to the impact of IS in society (*TDT4252 - Enterprise Architecture for Enterprise Innovation*, 2022). Students should acquire the skills to analyse business and enterprise situations using Enterprise Modelling skills. The curriculum covers Enterprise Modelling and Architecture, Innovation, Service Design and Business Modelling methods. Hence, the course is designed as illustrated in Figure 1, where students first learn to analyse business and enterprise situations and model them using Enterprise Modelling and Enterprise Architecture methods. The students are required to identify a real or a realistic case to model, which they find motivating. Then, they are asked to innovate their enterprises using ideas from Open Innovation (Chesbrough, 2011), Service Design and through incorporating digital technologies. They are then required to refine their enterprise models to include the new innovations and services. An example case could be a shop that has challenges in keeping an overview of their stock and the sales personnel do not have an overview

of the stock or have a good means of updating the stock based on the sales. An innovative idea could be the introduction of a mobile application to support this process, where the shop personnel as well as the customers could benefit from the innovation.
As one of the main skills that the students should acquire is Enterprise Modelling, the first two steps (in Figure 1) focus on this. It is a complex task with several sub-learning goals, e.g. learning modelling skills and understanding the broader business and social context of an enterprise and this task could have a high cognitive load (Sweller, 1988) on the students.

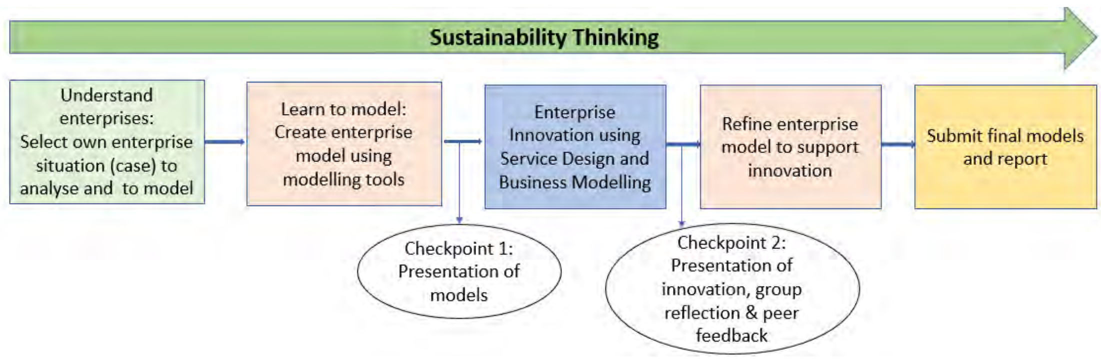

Figure 1. Course design and overview

The course work includes working on the case and the enterprise model throughout the semester. The final grade is based on the final models, a report and a few learning activities, such as presentations in checkpoint 1 and groupwork in checkpoint 2.

CDIO and Optional Standard 1

The course includes elements from many of the CDIO standards (CDIO Office, 2022b) as shown below:

- Standard 3 - Integrated Curriculum: Students participate in group activities, do presentations, provide feedback to one another and do peer reviews to develop inter-personal skills such as communication and providing constructive feedback.
- Standard 5 – Design-implement experiences: Students design and implement Enterprise Architecture models and customer journeys and blueprints for their innovations and improve them through feedback from peer students and the teaching staff.
- Standard 6 – Engineering learning workspaces: Students engage in appropriate group learning activities, which serve as workspaces to support reflection and social learning.
- Standard 8 – Active learning: Students contribute to the learning contents by identifying and describing their cases to model, which are unique and contributions by the students. They also define their own innovation for their case enterprises. Furthermore, they engage in active learning experiences through group discussions, presentations to the whole class and their groups and peer feedback.
- Standard 11 – Learning assessment: Students are assessed using a variety of methods and through several activities. Their analytical and modelling skills and knowledge are assessed through their models and the final report. Participation in the numerous activities designed to develop interpersonal skills (CDIO standard 3) are taken into account in the overall assessment.

Most importantly, CDIO Optional Standard 1 – Sustainable Development (CDIO office, 2022a) has been implemented. Sustainability is integrated as a part of the curriculum and is presented as an essential part of the topics taught is the course. Learning activities are designed to support students' awareness and understanding of sustainability as an important topic in their future work. It is also integrated into the final assessments of the students.

INTEGRATING SUSTAINABILITY THINKING

Since 2020, we have integrated Sustainability Thinking into the curriculum. We have taken a step-by-step approach to introduce the basic ideas and to incorporate them into the learning outcomes and learning activities, which is shown in Figure 2. Our overall approach has been the systematic integration of sustainability into the existing syllabus rather than introducing an additional topic on sustainability. In the first two steps of the course (as shown in Figure 1), the students were made aware of the importance of sustainable enterprise solutions. Students are asked to bring their own enterprise cases to model, empowering students to contribute with learning resources and to create interesting and challenging discussions among them. Empowering students as a part of their learning process can enable the development of their critical thinking skills (Cheah et al., 2022). The focus on sustainable innovations, services and solutions, where sustainability was presented through its many definitions and perspectives (e.g. economy, environment, society), was during step 3 (in Figure 1), when the students had to innovate their enterprises through developing a new service using digital technologies, and create sustainable business models for the new service(s).

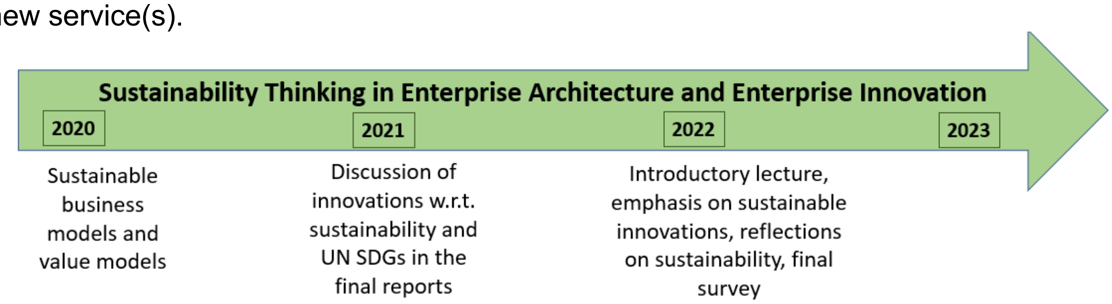

Figure 2. Step-by-step integration of Sustainability Thinking into the course

In 2020, we started by identifying the topic in the syllabus where it was easiest to integrate sustainability ideas (the low hanging fruit), which was business models. Methods for creating sustainable business model were available at that time, such as the Triple Layered Business Model Canvas (Joyce & Paquin, 2016) and the Flourishing Business Model (Van den Broeck, 2017). In 2021, we emphasised on sustainable innovations by introducing the United Nations Sustainable Development Goals (UN SDGs), through class discussions and by asking the students to describe how their enterprise innovations may affect the UN SDGs. In 2022, we built upon this by presenting a lecture on sustainability at the beginning of step 3 (in Figure 1).

We also introduced a group activity, labelled as Checkpoint 2 in Figure 1, which included students' presentations of their innovations including how they relate to UN SDGs, peer feedback and group reflections. Furthermore, we have included students' reflections on sustainability related to their cases as a part of their final report, and included sustainability related questions in the final survey, designed to obtain feedback on the course.

RESULTS AND EVALUATION

The main aim of the evaluation is to assess if the students have increased in their awareness of Sustainability Thinking during the course, and if they have been able to relate their enterprise cases, their models and the design of IS systems (digital solutions) to sustainability. After the enterprise and innovation step, at Checkpoint 2 (in Figure 1), we conducted a Mentimeter survey (an online, interactive survey tool) where we asked the students what new knowledge they had gained from the Checkpoint 2 group activities. The Wordcloud of the responses showed sustainability as one of the bigger and bolder text, indicating that several respondents mentioned it. 30 students (70% of the class) responded to the Mentimeter survey.

In the final survey at the end of the course, students were asked to indicate their level of agreement to a number of statements related to Sustainability. 20 students (46.5% of 43 students who completed the course) responded to the final survey, and the results are shown in Figure 3. Based on these responses, while it may be hard to claim that students have increased their awareness of sustainability from this course, it is reassuring to see that most of them Agree or Strongly agree that Sustainability is important to them in their future work as designers of innovative solutions and ICT systems. More importantly, 65% of the respondents (13/20) agreed to the statement “I think this course has increased my knowledge of sustainable innovations in enterprises”. Furthermore, 5% of the respondents strongly agreed and 35% of the respondents (7/20) agreed to the statement “I think this course has increased my awareness of sustainability”.

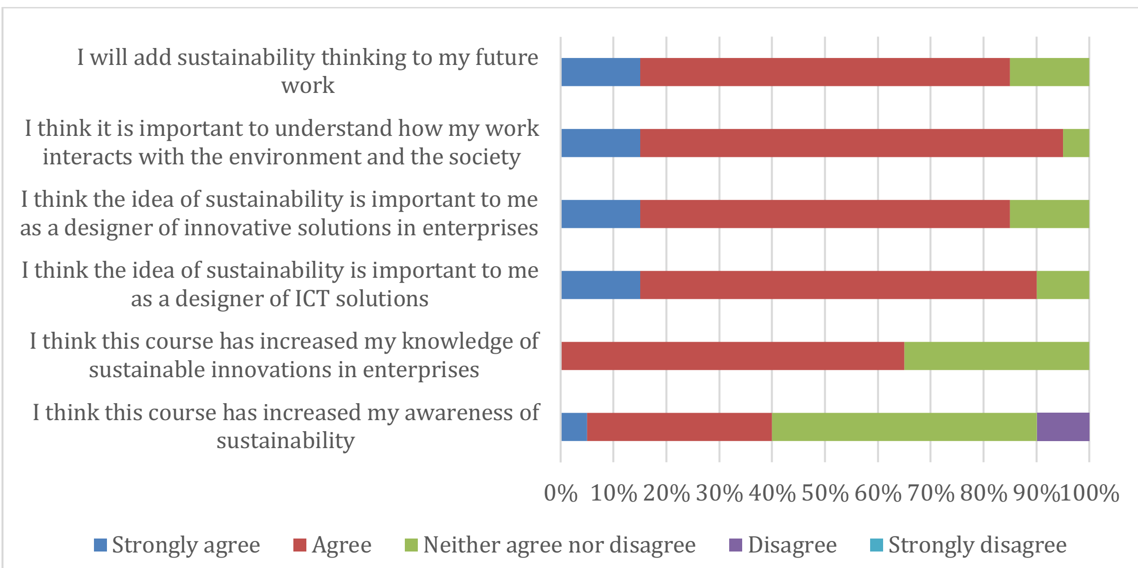

Figure 3. Students’ responses to Sustainability related questions in the final survey

A possible explanation for these results could be that students are, in general, aware of sustainability and therefore their awareness was not necessarily increased by this course. Note that the background survey conducted at the beginning of the course indicated that 3.3% of the respondents have had previous courses that relate sustainability to ICT, and 13.3% have had courses that related to sustainability. The global and the university’s focus on sustainability, where sustainability is one of the university’s strategic areas, may also have contributed to the students’ general awareness of sustainability, prior to this course. However, awareness about a subject does not indicate that they have knowledge about the subject, where knowledge includes facts, information and skills. The students may lack the basic knowledge about sustainability, in particular, the knowledge about sustainability in the context of innovations in enterprises, which is the subject of the course reported in this paper. The responses to the statement “I think this course has increased my knowledge of sustainable innovations in enterprises”, indicate this.

The results also show that a high percentage of the students (85%-95%) of the students agree or strongly agree on the importance of sustainability in the design of ICT solutions and that it is important to understand how their work interacts with the environment and the society.

LIMITATIONS OF THE STUDY

This study is limited as it has been conducted as a part of the evaluation of the overall course and not as a study focused on teaching sustainability. Hence, the part of the survey that was related to sustainability was limited and did not ask detailed questions about the topic of sustainability. Therefore, the results do not provide a precise understanding of the students’ knowledge or the depth of their knowledge about sustainability. Furthermore, it was voluntary to respond to both the background survey at the beginning of the course and the final survey, and the participants were not identified. Therefore, a baseline for the results shown in Figure 3 was not available.

One of the weaknesses of this data is the low number of respondents. Students seem to experience survey fatigue due to the abundance of online surveys they are asked to complete. The end of the courses is also when students prepare for their exams and thus, the survey may have been seen as an interference in their exam preparations.

CONCLUSION

This paper describes how Sustainability Thinking has been integrated into an IS course on Enterprise Architecture for Enterprise Innovation, which is a Masters level course at university, offered by the Department of Computer Science. The main research question addressed in this paper is how to integrate Sustainability Thinking into an IS course on Enterprise Architecture and Enterprise Innovation. The paper describes the step-by-step approach taken in the course to introduce sustainability and relate the concepts to the contents and learning activities of the course such that sustainability is integrated into the curriculum. The evaluations show that the students have increased their awareness of sustainability and consider that it is important to include Sustainability Thinking in their future work as designers of IS solutions.

Our plans are to enhance the integration of Sustainability Thinking into the learning goals, the curriculum and learning activities in the course. We aim to seek insights from literature and experience from other teachers that could benefit our teaching approach. One of the main challenges that we need to address in the future is how to assess if the students have acquired an understanding of sustainability related to their subject and if we have indeed achieved the desired learning outcomes. We are also working on improving the means for assessing the knowledge and attitudes of the students.

Given the urgency of incorporating Sustainability Thinking into all our courses, this step-by step process may not be the most effective approach. We hope that this learning experience could help other teachers in designing more effective means of integrating sustainability into there IS and other courses.

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BIOGRAPHICAL INFORMATION

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III Engineering Education Research

NETWORKING CHANGE LEADER – NEW ROLE FOR A PROGRAM DIRECTOR IN ENGINEERING EDUCATION

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ABSTRACT

Calls for changes in higher education are omnipresent and motivated by major challenges for society. Several of these challenges, for example those related to digitalization and sustainability, falls into the category of emerging and transformative challenges. The breadth and width of such challenges is too large to be handled by a single individual or even a small group of individuals. Instead, their solution requires an adaptive leadership with relevant activities at all organizational levels. From research literature and previous successful change processes, it is known that change leaders in the middle are key players during such transformations. In engineering education (and in fact in any other education aiming for a profession), it is natural that this role is taken by a program director who already has a responsibility for the quality and the development of an engineering program.

In this work, I will approach the role of a program director from a logical perspective using arguments based on a simple comparison between available time and total time required to create the desired change. It is obvious that large challenges demand a substantial amount of time to find an acceptable solution, which is outside of the reach for any single individual. I will also discuss the crucial role of persons in the middle for obtaining successful change related to large challenges. Based on my own case, I will try to give some advice about how a program director in the role as a person in the middle can handle this pressing situation. I will point towards the needs of personal time management, a basic understanding of agile change management, the ability to create structures and collaborative efforts that promote agile actions, the need for making coherence and using inclusion strategies and the necessity of networking. I will also emphasize the importance that universities support internal and external networking structures.

KEYWORDS

Engineering education, change management, role of program director, Standards: 3, 9, 12.

INTRODUCTION

Presently, there are strong societal demands for changes in higher education as manifested in debate articles (Mintz, 2019; Kurshan, 2020) and guest editorials (Martin et al, 2022). However, it has also been recognized that change must occur in a thriving atmosphere (Lake & Buelow, 2021) to conserve the well-being of those involved in the change process. On a general level, there is a strong demand from society that higher education should educate a new generation of individuals who can solve today's global challenges (Schmelkes, 2022, Martin et al, 2022). This also affects engineering education at the same time as there are many other challenges to address for example related to the ongoing digitalization (Brooks & McCormack, 2021), globalization (Varghese, 2013) and the need for introducing better ways of student-centered learning (Kober, 2015; Waldrop, 2015). All these factors contribute to demands for substantial change of both goals, content, and format of delivery in engineering education, which put severe pressure on all levels in the organization, something that became apparent when analyzing the emergent teaching during the pandemic (Graham, 2022). Hence, it is urgent to find ways to handle and manage this complex situation in an efficient way and to put this development into some simple and understandable context.

From management literature, it has for a long time been known that large scale changes are hard to manage (Kotter, 1995). This has also been experienced in higher education, where resistance towards change occurs from many factors as for example senses of territory, issues related to time and resources, long-lived traditions, individual fear for threats against autonomy and shortcomings in leadership or communication (Chandler, 2010). On the other side, there has been several attempts to identify success factors for obtaining sustainable systemic change in higher education and some of those factors are:

- Initiation created by a response to a common set of circumstance (Graham, 2012) or through an internal crisis becoming obvious to everyone from external input (Cohen et al, 2003).
- Coherent and interconnected curricular structure (Graham, 2012; Crawley et al, 2007).
- Leadership support from department heads (Graham, 2012; Cohen et al, 2003).
- An ongoing focus on educational innovation and reinvention (Graham, 2012).
- A flexible organizational culture (Kleijnen et al, 2014)
- Connection to teacher's day-to-day work (Kleijnen et al, 2014)

Another approach is to consult the extensive research literature on change management. Due to some issues related to the use of change theory in STEM higher education (Reinholz, White & Andrews, 2021), I will for the moment postpone this discussion and instead base my argumentation on some logical facts related to limitations in the use of time:

- Time goes equally fast for everyone, which put limits on the time a single individual can spend on solving a challenge.
- Small challenges are then within the reach of single individuals or a small group of individuals.
- Large challenges are time-consuming and, hence, they require the involvement of many cooperating individuals.
- Large challenges often involve more advanced human skills like learning, design and innovation, which further increases the required time.
- Clever division of workload between individuals reduces the time for finding a solution.

On top of this, limitations in available resources require that challenges are solved in an efficient way. For human-intense activities like education and educational development this usually comes back to limitations in available time, which was found as one of the factors creating resistance against educational development (Chandler, 2010). When the total required time is within the reach of a single individual or a small cooperating group of individuals, we essentially already have the tools and methods to solve such challenges. Teaching students these skills have traditionally been a strong part of an engineering education and is an integrated part of traditional engineering values. This is also reflected in how universities are built up around independent small and middle-sized research groups.

Nowadays, society also expects higher education to educate students who can tackle large challenges related to for example sustainability and digitalization. The solutions to such challenges require the cooperative effort of many individuals, which means that the total time spent on finding a solution is larger than what can be accomplished by a few individuals in a reasonable amount of time. Hence, the solution to such problem also includes the skills to cooperate. Since universities are traditionally not organized to solve such challenges, it explains the resistance related to traditions and sense of territory identified by Chandler (2010). Furthermore, if excessive time is spent due to bad management of the cooperative effort, resistance is created due to leadership and communication issues (Chandler, 2010).

The complexity of the problem also makes it impossible for managers at the top level of the organization to steer the development in detail, since they do not have a sufficient overview of all details and it is also impossible for them to a priori forecast the usefulness of innovative ideas created locally within the organization. Hence, one-directional top-down management approaches are undesirable in these situations (Heifetz, Grashow & Linsky, 2009). On the other hand, locally found innovative ideas may conflict with overarching goals and may need to be adapted (or in some cases even rejected) when transferred into new circumstances.

In this work, I will restrict myself to discuss large challenges and what consequences they have for a program director (or for a person in an equivalent position) of an engineering educational program. Since it is usually part of the responsibilities of a program director to lead future development in an educational program, it is clear from the arguments above that a program director must mediate between several perspectives where some may be contradictious and others may require larger change efforts than can be handles within a small group of people. The solution to such challenges requires the use of adequate change management skills and strategies at all levels. Finally, I will try to give some answers to the question how a program director can handle such a pressing situation.

CHANGE MANAGEMENT

This work is about how to handle large complex challenges, which are complex in the sense that reaching a sufficiently good solution is time-consuming, involve many people and require that those people learn new things during the change process. In engineering education, two examples of such challenges are how to device efficient learning activities for sustainability and how to use digital tool in the best way to enhance learning. For *a single individual human being*, these challenges are overwhelming to handle (due to time constraints), but the challenges should be manageable for a larger group of people who collaborate in a time-efficient way. The question is then how to set up and sustain such a large-scale cooperative effort?

Since there are inherent limitations in how many social relations an individual can sustain (since building social relations takes time and time is a limited resource!), complex problem solving is often handled through hierarchical structures. That implies that each level in the hierarchy only involves a manageable number of social relations. This type of collaborative effort between many individuals should work if the problem-solving methodology is a priori known. However, for challenging problems this is not the case, which implies that some type of organizational learning strategy is also needed to attain sustainable change (Boyce, 2003). In the Organizational Learning Framework (Crossan, Lane & White, 1999), innovation is considered as a key mechanism for development. This framework suggests an intertwined process between three levels in the organization (the individual level, the group level, and the organizational level) where individual ideas are grouped and forwarded upwards in the organization (bottom-up) at the same time as the organization monitors and handles the change process (top-down). When applied to higher education, Rikkerink et al (2016) has pointed out the need for proper leadership practices in the nexuses between the three levels in the Organizational Learning Framework.

The Organizational Learning Framework is centered around a hierarchical approach to achieve efficient information flow in two directions (bottom-up and top-down) with the overall goal of creating organizational learning. However, this framework does not consider the potential benefit of cross-links in the information flow created by networks. The positive links between networking, innovation and competitiveness are well established in industrial management (Pittaway et al, 2004). In a similar manner, the interwovenness of structural-agentic processes and the usefulness of academic freedom as room for maneuvering in curricular change in higher education has been pointed out by Annala et al (2021). This indicates that social interactions between people in the middle is an important factor for organizational learning in higher education.

This is in fact not at all surprising when considering that time is a limiting factor for all human beings. Hence, top managers do not have the time to overview all the details and individuals do not have the time to be active in the development of all new things. This directly puts the focus on the crucial role of people having positions in the middle and how they should act to support and enhance organizational learning. Logically speaking, their role is then to create coherence between top-down and bottom-up views within the organization and to ensure the efficient use of time (or equivalently human and economic resources). From studies of successful change processes in K-12 education, coherence has been seen as a key factor for success and is defined as a 'shared depth of understanding about the purpose and nature of the work' (Fullan & Quinn, 2016; Fullan, 2020). The role of the 'leaders in the middle' is then to establish 'a philosophy, structure and culture that promotes collaboration, initiative and responsiveness' (Hargreaves & Shirley, 2020). Similar ideas have also been put forward for change in higher education, where the importance of balance, sense-making, and interconnected strategies have been noticed (Kezar & Eckel, 2002).

However, the situation for higher educational institutions is even more complex. In a UK context (and probably in the context of many other countries as well), a majority of engineering academics and researchers find that teaching is afforded little or no value in academic promotion procedures (Graham, 2015). With a perceived low value, it is no surprise that change in higher education to a large extent will be driven by rather lonely and devoted educators. Due to their own time constraints, those educators can only approach challenges that are solvable on the individual or small group levels. This points towards a systemic weakness in the ability to handle large challenges, which are characterized by the cooperation of a larger number of people than is available on the local level. Hence, it is no surprise that change in higher education is perceived to be slow and difficult to manage. In fact, large systemic change seems to either occur under a considerable external or internal pressure that creates common sets of circumstances (Cohen et al 2003; Graham, 2012) or through a deliberate combination of vision creation, coalition formation, communication, faculty empowerment and culture consolidation (Jiang, 2022). Both these approaches have in common that they use motivating factors (threats or visions) to mobilize a sufficiently large workforce to meet the challenges within a reasonable time by sharing the workload.

In a recent review article, Reinholz, White & Andrews (2022) draws the conclusion that earlier attempts to use change theory in STEM higher education have mainly been based on theories for individual change instead of theories that also considers the system in which the change takes place. They identified a lack of theoretical coherence, a greater need to focus on diversity, equity and inclusion and the need for formal opportunities for scholars to learn about change and change theory (Reinholz, White & Andrews, 2022). There is also some evidence that more generic change models stemming from industrial management need to be somewhat modified when applied to higher education due to institutional and cultural differences (Jiang, 2022).

Since higher education involves many disciplines with varying scientific traditions, there are also a larger need for local adaptation during change as compared to other areas of society. Hence, time-limiting arguments for top managers in higher education makes it even more impossible for them to control all the details during a large change process. Once again, the leaders in the middle become essential for the development suggesting a distributed leadership model (Jones & Harvey, 2017). However, time is also a limiting factor for people in the middle which implies that they need some sort of support to be able to fulfill their duties to create coherence between local traditions and overarching goals during a change process. These insights are also reflected in recent research about change processes in higher education, which discuss questions about how to enable educational innovation and change through complexity leadership (Schophuizen et al, 2022) and how to use various strategies of promoting networking to boost the development (Stasewitsch, Dokuka & Kauffeld, 2022; Högfeldt et al, 2022).

THE ROLE OF THE PROGRAM DIRECTOR

For an engineering education program, the role of the leader in the middle is in most cases taken by a program director. The simple reason is that top leaders do not have sufficient time and putting all the responsibility on all teachers will give them too much workload, which causes risks for their health. Hence, neither a top-down solutions nor a solution where all pressure is put on individual teachers will work in practice. The duties then fall on the program director considering the evidence from change literature that leaders in the middle are crucial for obtaining sustainable change. However, time limitations also apply to a program director who is in an even more difficult position having to moderate and create coherence between overarching goals, local traditions, innovations, and local suggestions for change in an engineering program. Hence, a central question in this work is how a program director can handle such a pressing situation?

The research literature on the role and actions of a program director is very limited and usually deals with other aspects like for example the balance between formal and informal power (Högfeldt et al, 2017) or looks at the development through the lenses of executive coaches (Vlachopoulos, 2021). Here, I will instead use my own case based on six year's experiences as a program director of a master program – a duty that is expected to take 22% of my time. When taking over these duties in 2017, the local faculty was hesitant to to any change due to a successful evaluation of the program in a national review (UKÄ, 2013). Today, they have become more agile and participate in the development of the program at the same time as the number of students has increased by 25%, indicating a successful change process.

The main challenge as a leader in the middle has been my own time limitations, which imply that I can neither be involved in following all development trends nor be able to do all the necessary work at the local level. A primary priority has been to ensure that the time reserved for my duties included a reasonable amount of time for reflecting about and leading program development. A constructive dialogue between the program director and leaders within the organization may help to give the program director the necessary time and mandate to lead educational change. However, a faster approach is to reconsider how to save time spent on routine tasks and documentation (without reducing quality). Another issue is to streamline the information flow within the program to reduce unnecessary questions. Also, a program director should use a minimum of time to obtain all relevant information about the program that is required to take informed decisions about complex challenges. In the long run, relevant information can be made available from the university, but the university does not a priori know what information the program director need. If relevant information or efficient processes are missing, they may need to be developed. An example of this is the procedure to include student views in an efficient way for program development (Leander Zaar and Andersson, 2020), which was developed by a student with me as project leader. For larger projects, a constructive dialogue among program directors and managers is necessary to ensure an efficient use of resources and to create coherence in the organization.

When time is redistributed towards leading educational development, a program directors' role is to take a broad view of the program including several perspectives and to use relevant information to identify potential points of improvements that are *essential for improving the program*. Engineering education programs aspires to educate engineers for different roles in society, which require different knowledges and skills. However, suggestions for change from top managers or from single individuals are perhaps not beneficial for the specific program. This is not surprising, since time limitations promotes suboptimizations of a problem. To be time efficient, a program director needs to filter the information flow and prioritize those issues that are most beneficial for program development. Furthermore, a program director also needs to be pro-active and gather relevant information about novel educational issues to make informed strategic decisions. Being curious and networking with other people is a rather efficient way to get informed.

When it comes to the implementation phase, a program director is responsible for getting the work done but does not have the time to do all the required work. Since other people should do the main work, it is a crucial issue to consider how to organize the change process (who should be involved and how to distribute the workload) to be efficient. For implementations that require a small number of people, it is sufficient to give them the mandate and the main directions to come up with a solution. An example from my own practice is that I give the mandate to a relevant group of teachers to suggest a revision of the course structure for a track within the program. I designate a coordinator for the task and help the coordinator to get funded. I set up relevant program level limitations for the work and demand that their suggested solution should fulfil these limitations and solve known issues. Furthermore, I demand that the working principle for the group must be inclusive and involve opinions from all teachers within the track and from students. The inclusive strategy assists in building trust, keeps up motivation and helps to set up a good climate for change. During the work, I check that the work is progressing and do not interfere with program goals, giving the group a large freedom to come up with innovative ideas. Three out of five tracks have so far been changed in this way.

This works for small and medium challenges. However, when it comes to large challenges, a program director needs to be personally involved in the work. The simple reason is that large challenges also require that a program director must learn new things. In fact, this is a characteristic feature of this type of challenges (Heifetz, Grashow & Linsky, 2009). Since personal involvement is essential (no one else knows the program aspects as well as the program director), the program director needs to gather information and is responsible for strategic decisions. To use time in an efficient way, only ideas that are relevant for the development of the specific program are condensed and forwarded to a group of teachers and students working on the problem. Based on the results of such discussions, it is possible to continue by starting small development projects. Obviously, a program director has time limitations and should not be left alone during the overarching work. Hence, it is important to spend some time on networking, where large challenges can be discussed and where one can learn from each other's experiences. In the ideal case, these networks are set up and offered by the university (Stasewitsch, Dokuka & Kauffeld, 2022; Högfeldt et al, 2022), but taking part in external networking which for example occurs during the CDIO Conferences is also a pathway for getting ideas for further development.

CONCLUSIONS

I have shown that inherent time limitations when solving large challenges puts the role of a program directors into a new context. Since such challenges involve organizational learning, the role of a program director as an agile change leader becomes apparent. This implies that in the future, program directors need to have some basic understanding of the principles behind agile change management. Hence, they need to reduce the time spent on routine tasks to instead use their time to actively reflect on the role of the program for society, participate in networking activities and consider their role as 'leaders in the middle' when communicating with both managers, teachers, and students in the program. According to my own experiences, reflecting and analyzing time efficiency when working with change, has been useful both for me and for the teachers within the program in our work to improve the program.

LIMITATIONS AND FUTURE WORK

In this work, I have assumed that a program director is the natural person to lead change from the middle. However, other ways to manage complex change processes are also expected to work provided that the functionality to mediate between overarching goals and local cultures is preserved. Such a functionality can either be taken by a networking individual (working together with several program directors) or by a group of networking individuals. A few examples for such strategies are to form coalitions that jointly investigate new opportunities through pilot studies or to form coalitions related to common needs for change.

To keep up pace in a complex change process, several change initiatives need to run in parallel. This clearly goes beyond the time limitations of a single program director. Hence, a university needs to implement a coherent overarching structure to efficiently support 'leaders in the middle' with relevant data and with opportunities to network, learn from each other, and to join forces to solve large scale challenges (which are outside the scope of a program director). Furthermore, there is a need from university leaders to clearly communicate the needs for change and their reason for choice of change model to faculty. The framework for 'Future Education' (KTH, 2023) is one example from our university about how to approach these issues.

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FROM UNIVERSITY TO WORK: ALUMNI VIEWPOINTS

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ABSTRACT

Alumni studies are often overlooked in engineering education research, despite holding great potential for improving engineering programmes and creating the links that are missed when it comes to university-workplace transitions. Besides better understanding the strengths and weaknesses of the taught and learnt curriculum, being aware of the perspectives of the alumni contributes to identifying the array of knowledge, skills and attitudes graduates need for successful job integration. In exploring the Conceive-Design-Implement-Operate (CDIO) framework, there is a question: "[w]hat are the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency?" (Crawley et al., 2007:45). In this study, we intended to ask the same question. This paper presents the results of a part of an alumni survey which focuses on the skills they gained and the strengths and needs of the degrees they obtained. In the results, we noticed that more than 80% of respondents are highly satisfied with skills in the research domain, such as using maths, information skills, and research skills, while the less convincing are project management and teamwork. Skills related to sustainability, ethics and entrepreneurship, were identified as definite weaknesses. We experimented with the CDIO framework analyse the open-ended answers, where the most mentioned professional skills were real-life content and interdisciplinarity, while autonomy was the most frequent personal skill missing. Although the results indicate a lingering difficulty in developing a comprehensive and holistic curriculum in engineering education, there are a number of lessons we can draw from it both in terms of further efforts in developing academic offers and in terms of alumni-oriented research in fields of engineering education.

KEYWORDS

Alumni research; Work readiness; Competence frameworks; Program evaluation (12)

INTRODUCTION

There are not many reliable ways to determine the quality and worth of educational programmes and courses. Learning outcomes as presented through student exam success might not provide an accurate picture of the long-term retention nor the impact on knowledge, skills and competencies gained through courses, and, in many ways, examination and most of the summative assessments do not give a clear indication of the skills and attitudes students might have acquired during their studies. On the other hand, alignment of the educational programmes and courses with the external “value” points, such as accreditation bodies and their requirements might provide a stamp of quality for employers and industry, but given the ambiguous use of words and vagueness in pedagogical implementation (Junaid et al., 2022), they still might not vouch for the quality of teaching and learning experience.

Working on developing a relevant and coherent educational programme is the single common desire of all higher education institutions. Most engineering education institutions and programmes see a great deal of their purpose in providing “the learning required by students to become successful engineers - technical experience, social awareness, and a bias toward innovation” (Crawley et al., 2014, p.1). Hence, there is a recognised need and an imperative from all stakeholders, including academia, industries and governments, to continuously improve the quality and learning experiences within engineering education.

Alumni research is “designed to elicit individuals’ reflections about the quality of their education experience that are tempered by their experiences since graduation” (Pike, 1994, p.105). While this kind of research is not common or fully exploited in Europe in comparison to the US or UK (Saunders-Smits & de Graff, 2012), we can argue that there are aspects of this kind of research that are highly valuable for refining the quality of educational programmes. From the perspective of a graduate who has been involved in other life experiences, most notably their employment, it is valuable to understand if there is any connection between the two lived experiences - academia and industry. This might be even more interesting in highly practical domains, like engineering, where theoretical concepts mean very little if not applied adequately to a tangible situation. Thus, in this paper, we showcase our intention to understand better the educational programmes and courses through the words of alumni. We, as others have before us, question "[w]hat are the full set of knowledge, skills, and attitudes that engineering students should possess as they leave the university, and at what level of proficiency” (Crawley et al., 2007:45), even though we acknowledge that this might never be completely possible with our approach, nor with any other existing ones.

In the following sections, we provide a very brief insight into the relevant literature in an attempt to position our analysis and discussion. This is followed by a methodology section, an overview of the results and the conclusions.

LITERATURE PERSPECTIVES

We focused our study on the learning outcomes of alumni, and the competencies that alumni report as important for their work after graduation. With this in mind, we position our analysis within the three most relevant research domains: work readiness, competence frameworks and alumni research.

Work readiness

In general, there is a misalignment between graduates’ skills and competencies, and the labour market needs and demands of employers (Winterton & Turner, 2019). While there are large differences in terms of scientific and industrial domains, Winterton and Turner (2019) present a general overview of recent studies looking at satisfaction with educational programmes. Looking from the perspective of employers' satisfaction with graduates, there seem to be evident skill gaps, particularly with respect to transversal, personal and relational competencies. Mentioned among others are skills such as responsiveness to feedback, self-learning strategies, solving problems, but also communication skills, self-management and even team working. These points are well corroborated by more specific studies that focus on the viewpoints of graduates and supervisors in engineering education (e.g. Jollands et al., 2012).

A body of education research connected to work readiness often examines elements that form a gap between competencies acquired through tertiary education and competencies demanded by the world of work. Caballero et al. (2011, p. 41-42) define it as “the extent to which graduates are perceived to possess the attitudes and attributes that make them prepared or ready for success in the work environment”. Other synonyms include work preparedness and graduate employability, and these include a range of interchangeably used terms such as generic skills, core skills, basic skills, transferable skills and employability skills. The terminology might differ depending on the domain, however, Caballero et al. (2011) suggest a generic work readiness scale consisting of dimensions such as personal characteristics (e.g. resilience, adaptability), organisational acumen (e.g. motivation, maturity, attitude to work), work competence (e.g. technical focus, problem-solving), and social intelligence (e.g. interpersonal orientation).

Combining this overview with the more focused literature on the variety of professional roles graduates in engineering undertake (i.e. Trevelyan 2010; Brunhaver et al., 2013; Craps et al., 2017), it becomes evident that the technical knowledge and skills are not enough. Additionally, there is often a simplicity in how transversal skills are thought of which does not resonate with the needs of the professional setting. For instance, in their study Craps et al. (2017) noted that communication skills are often oversimplified in writing technical reports and preparing oral presentations. However, up to 60% of work-related communication of practising engineering can be seen through their interaction with professionals from other fields, other backgrounds and cultures, and the success of these interactions relies on good listening and collaboration skills (Craps et al., 2017; Trevelyan, 2010).

Thus, studies show that quite often the academic stakeholders see and agree on the issues of graduates being ill prepared for work (Winterton & Turner, 2019; Jollands et al., 2011). Saunders-Smits & de Graff (2012) found out that especially for managerial positions, there is a relatively high agreement from both alumni and employers on the importance of skills such as people management, oral communication, lifelong learning and analytical skills. Perspectives in trying to mend the identified gaps, such as work-based, work-integrated and project-based learning formats are only a few current best practices. Yet, these formats are less widespread and often not well scaffolded in order for students to consciously gain a wide range of skills, hence gaps persist even when such formats are in place.

Competence frameworks

Competence frameworks are currently best-known practices that ensure the upholding of quality standards within disciplines and professions. Most authors define competencies in a similar way - as personal traits or characteristics, sometimes also as skills, abilities and behaviours, that play an important role in work performance and delivery of desired work-related results (Prifti et al., 2017). However, similarities often end here. Different competence frameworks follow different logic in clustering, classifying and hierarching sets of specific competencies, and to date, there is no agreed approach that satisfies all educational stakeholders.

Results of a meta-analysis of studies using the Great Eight competency framework have shown moderate to good results in terms of how these competencies relate to employers and work situations mostly from a sample of management, technical and sales positions (Bartram, 2005). Elsewhere, competencies are separated into four categories, such as personal, social/interpersonal, action-related and domain-related in Erpenbeck and Rosenstiel model, or likewise classified at different levels, such as meta, domain, method and social competencies in Egeling and Nippa model (Prifti et al., 2017). In their literature review, Prifti et al. (2017) note that there are many models that are specific for a certain type of work, e.g. leadership and management, and that from the literature "communicating with people" is the competency that is most mentioned, followed by "IT/technology abilities, big data and problem-solving", and "lifelong learning, work in interdisciplinary environments". Beyond those in research papers, governmental bodies have also worked on their own competency frameworks, normally by applying methods to align human capital planning (education) with employment and organisational strategies (workplace), for example in France (Gestion Prévisionnelle des Emplois des Compétences - GPEC). Finally, stakeholders such as educational programme accrediting bodies play a role in suggesting what gets value in the programmes they accredit, yet this might heavily vary from context to context, and there are a few shortcomings in these as well (e.g. Junaid et al., 2022).

Developing "the model" in the engineering domain has been an accepted challenge too. Leslie (2016) for instance proposed a multi-tier hierarchical model which was developed by a team through a review of available information, including ABET and other bodies and societies, the current curricula and related resources, as well as experts from industry and academia. In their model at the base are the personal effectiveness competencies, including interpersonal skills, integrity, professionalism, initiative, adaptability & flexibility, dependability & reliability and lifelong learning. These are followed by academic competencies such as reading, writing, mathematics, science & technology, communication, critical & analytical thinking and computer skills, and at tier 3: workplace competencies (such as teamwork, planning & operating, creative thinking, and problem-solving). Tier 4 and 5 are the industry-wide technical competencies (e.g. professional ethics, sustainability & societal & environmental impact, engineering economics), and industry-sector functional areas which are defined by industry representatives. Finally, at the top of this hierarchical model are the management competencies and occupation-specific requirements, the latter being defined by the domain, and the prior including skills such as networking, entrepreneurship, and managing conflict & team building (Leslie, 2016).

In a similar attempt to get unique model competencies for engineering education, CDIO was developed underlying a "critical need, recognised through dialogues between academia, industry and governments, to educate students who are able to Conceive-Design-Implement-Operate complex, value-added engineering products, processes and systems in a modern, team-based environment" (Crawley, 2007, p.1). The added value of the CDIO model is that it looks in detail at the engineering lifecycle from the point of conceiving ideas, such as in business strategy or customers' needs, all the way to operating which includes evaluation and system improvements but also logistics, recycling and upgrading. Recognising that an innovation process is being able to conceive, design, implement and operate systems in the enterprise, societal and environmental context, the model upholds UNESCO's four pillars of education: learning to know, learning to do, learning to live together and learning to be (Crawley, 2007, p. 54). In our analysis, we were particularly inspired by the CDIO syllabus and the three levelled structure that it proposes, particularly covering (1) disciplinary knowledge and reasoning, (2) personal and professional skills and attributes, (3) interpersonal skills: teamwork and communication, and (4) conceiving, designing, implementing, and operating systems in the enterprise, societal and environmental context - the innovation process. This framework was detailed and wide enough for us to engage in a more exploratory way.

Alumni studies

In the university ecosystem, there is a lot of attention to student learning outcomes. In almost all cases and for all taught content, the learning outcomes are assessed at the immediate end, through examination and assessment. The bottleneck of exams is that they might not accurately evaluate student learning, but rather students' ability to recall from memory under a great deal of stress. Alumni research is, on the other hand, done partly with the same aim to evaluate the learning outcomes but in a retrospective manner and from a point of view where graduates had other different experiences than studying.

The relevance of alumni research was first picked up by Pace who in 1979 identified the slow rise of this kind of educational inquiry (Delaney, 2000; Cabrera et al., 2014). In the early exploration of the focus of alumni studies, about 70% focused on competencies and the remaining 30% on alumni satisfaction and the relationship between education and employment (Cabrera et al., 2014). In her paper, Delaney (2000) explores the potential of using alumni research to assess graduates' preparedness for the demands of professional work and changing face of the labour market. She points out, "a unique feature of alumni surveys is the capability of documenting students' assessment of the quality of their educational experience tempered by their experiences since graduation" (Delaney, 2000, p. 139). There is much value in the notion that graduates gain first-hand experience in professional practice and are capable of contrasting that with their abilities to answer the demands.

Furthermore, alumni studies can provide more information about the various careers graduates undertake, as much as it can show the level of alignment between employers', academics' and graduates' positions and positionalities. Furthermore, as an evaluative model (e.g. Bisagni et al., 2010), well prepared alumni studies may result in valuable insights that can help modify the educational offer, both in terms of content and in terms of pedagogical approaches. Apart from pointing to slight differences in what is important for experts and alumni in managerial and specialist roles, Saunders-Smits and de Graff (2012) also give an example of how an alumni study was used to bring changes to the existing Aerospace Engineering programme at Delft University.

METHODOLOGY

Context and the tool

At EPFL, alumni surveys are part of the institutional data collection process. A specialised institutional unit, Career Centre, has been in charge of administering a standardised alumni survey which would serve institutional leadership to gain a general feeling for the trajectories of its graduates. These surveys are carried out each year, reaching alumni that have graduated one year ago. However, besides this, the Alumni Department has been working together with the Teaching Support Centre on delivering a special alumni survey that longitudinally collects data on alumni from the point of knowledge and skillsets gained and their needs during their education and their workplace. This survey is administered every 5 years with an objective to monitor and improve the content of the educational courses and programmes offered by the institution and as such is tied with the process of accreditation (c.f. Wiklnd et al., 2005; Bisagni et al., 2010). In this research, our focus is on the latter survey which is oriented towards knowledge and skills.

The structure of the survey is two folded. The survey is sent out to all alumni the same, and depending on the year of graduation, a part called "education assessment" changes slightly in terms of questions asked. The alumni that have graduated within the period of last five years since the survey (i.e. 2014-2019), are asked more detailed questions about the "offers" of the educational programmes, while those that have graduated beyond five years (i.e. 1980-2013) are asked one more generic question about skills needed for industry. For the purposes of this paper, we are only focusing on the section on education assessment and particularly on the self-assessment and opinions about knowledge and skills. The structure of most of the questions remains the same for the alumni of 1980-2013, with a change in the two open-ended questions.

The reason behind having this distinction and relating it to the year of graduation is that we can assume that alumni that have graduated more than five years ago would not have a clear memory and awareness of the curriculum in place. However, it is still valuable to know their opinions on the skillsets they assess necessary for the industry, hence the alternated question.

Data collection and analysis

Data was collected by means of an email sent out to the former students of EPFL through the alumni database. The email was sent in December 2021 to 18765 alumni that have graduated in the period from 1980 to 2019. The email contained a unique link and no identifying information was requested from respondents. Out of 18765 alumni, 2830 provided validated responses. The data was then separated into two graduation groups according to the previously set survey structure: alumni of 2014-2019 (n=908, response rate of 16.3%), and alumni of 1980-2013 (n=1922, response rate of 14.5%).

For both alumni groups, the close-ended answers were analysed quantitatively by applying simple descriptive statistics. The two open-ended questions for 2014-2019 were analysed qualitatively using MAXQDA, and manually coded by three researchers, authors of this paper. The researchers undertook two rounds of internal coding validation by each coding the same 20 answers. After each iteration, the researchers met to discuss discrepancies which resulted in an aligned codebook. Coding was done through a mixed approach, deductively and inductively. The researchers drew inspiration from the CDIO framework and in the first iteration wanted to test how some of the competencies in the CDIO framework could be used for coding and analysis.

Once the codebook was developed for the alumni group of 2014-2019, the same framework was used for analysing data of the “older” group 1980-2013. Since in this group, the respondents had a choice to input three lines of answers corresponding with a question about three top skills, we applied R to generate the list of words that appear in the answers using 1-word and 2-word structure. In the next step, clustering using a 2-word structure was done using the same CDIO-inspired coding framework, resulting in the final results for this alumni group.

Limitations

This paper shows an exploratory use of CDIO with an attempt to analyse and understand data, and as such we are aware of the limitations it contains. For the start, we used CDIO as a framework for analysing the strengths and needs of educational programmes that do not necessarily apply this method in its forms of instruction and content. While this may lead to a mismatch in our analysis, our main objective was to experiment with applying the CDIO framework and understand what general gaps the education programmes might have, as well as how aligned might the programmes be even if not applying the model in the first place. Additionally, with alumni data from 1980-2013 where the analysis was done using R, we recognise that there might be some data that could have been taken out of context. The 1-word and 2-word structure supported an easier analysis but we admit that there might have been longer textual answers that could have been missed.

In terms of limitations for the type of study, there are obvious questions about the reliability of alumni self-reported assessments. Pike (1993) asks "can they be trusted" and the answer is both "yes" and "no". Indeed, as the study shows, the more senior alumni become, the less accurate the reflections around their study programmes are. The same is true with job satisfaction and level of perceived accomplishments at the time of answering the survey - there is a positive correlation between university experience and employment experience, hence, alumni who are unsatisfied with their employment, working conditions or accomplishment status tend to evaluate their education in a more negative pattern (Pike, 1994; Carbera et al., 2014). In order to manage the limitation around alumni studies, questions related to education assessment were modified in a two-tier system depending on the year of graduation, as explained in the section above.

RESULTS

In this section, we first present the results of the alumni of 2014-2019, followed by comparisons to opinions given by the alumni of 1980-2013. In our presentation of the results, we will as much as possible use the words of the respondents from the open-ended questions about the strengths and needs of the programmes in order to expose the experiences in their own words. The quotes offered in the text are identified by a respondent's number and the section of the question (e.g. respondent 21, a question on Strengths / Needs).

Results: alumni of 2014-2019

When assessing the level of competence in core areas, out of 908 respondents only up to 9% answered they found it insufficient in relation to their work situations (0.5% mathematics, 1.8% physics, 6.3% chemistry and 8.9% computer science). Overall, the respondents seemed very satisfied with the "*very strong theoretical knowledge*" (455, Strengths). The education experience at EPFL seems to bring a recognised "*exposure to strong scientific facts and ways to solve problems*" (315, Strengths) and a "*strong foundation in science and critical thinking*" (141, Strengths). EPFL education is seen as strong in its "*high rigour, breadth of knowledge, state-of-the-art research*" (384, Strengths).

Similarly, when asked about scientific or technical gaps, 52% of the respondents did not select any of the multiple-choice items which points to a relatively moderate satisfaction level in terms of quality of scientific and technical curricular content. The education experience provided "*analytical skills and ability to grasp technical concepts quickly*" (368, Strengths), and capacity for "*critical thinking, and strong theoretical background*" (1657, Strengths). Open-ended comments corroborate the numeric results in telling a story of "*strong theoretical courses in all science subjects leading to good critical thinking and problem-solving approach*" (1918, Strengths) and alumni in general feel they had a chance to "*develop a structured way of thinking and being able to find information and learn fast*" (271, Strengths). Among the selected items, programming and software development appeared in 22% of responses and modelling/machine learning in 13%. All other items were selected less than 10%.

On the other hand, when asked about their level of competence with regard to professional skills, alumni of 2014-2019 seemed less confident, particularly around skills like "*teamwork, entrepreneurship skills, environmental sustainability knowledge and skills*" (384, Needs). Project management skills were frequently mentioned, in addition to "*fundamentals on sustainability and critical thinking on the role of engineers for climate and biodiversity issues*" (2658, Needs).

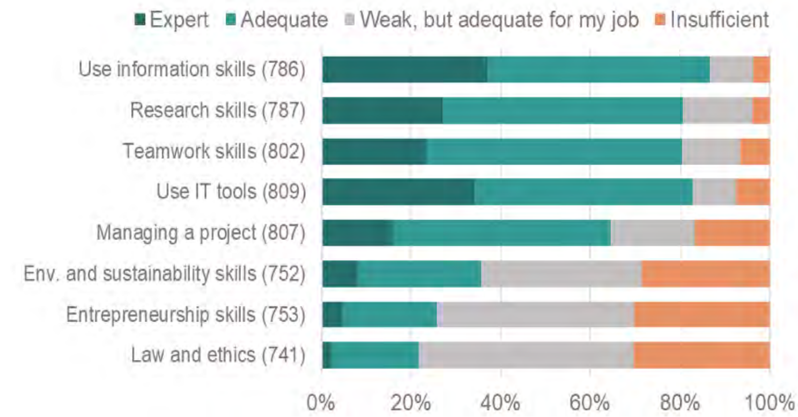

Figure 1. How do you assess your level of competence in these core areas at the end of your education at EPFL?

This result corresponds directly to the question about gaps with regard to professional skills in Figure 2. For this question, more than 40% of the respondents mention having to additionally work on their project management and real-world experiences, while other gaps were felt related to social aspects of conducting projects, particularly around project management and "real world" experiences. Respondents strongly advocated for "*more mandatory internships*" (603, Needs) and "*more projects completed from beginning to end, closer to what you would get when working in the industry (but not in a research position)*" (3910, Needs). To have a more work-ready education, a suggestion would be to have "*way more practical experience: there should be a mandatory internship and more focus on 'real world' projects. EPFL professors need to create more networks with the industry not simply for project partnerships but also for students to work. Despite being one of the top of my class the only options I got were working overseas or doing a PhD - Swiss companies were simply not interested in a fresh graduate with little experience*" (1276, Needs). Also, "*mandatory basic training in finance, project management, sustainability*" (368, Needs) would positively reflect on job preparedness and as this statement complements:

"*Social skills are an important aspect of being an engineer and a human being living in society. It is important to know how to communicate, share, transmit, and understand one's ideas. Studying less technical fields also helps to learn how to communicate to other people who are not engineers. Travelling/studying abroad helps a lot to develop these characteristics*" (1007, Needs).

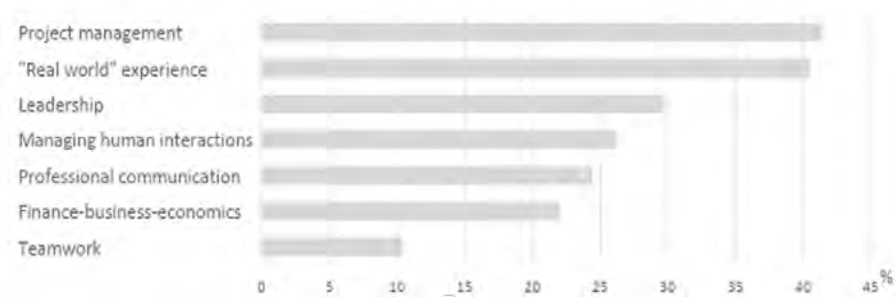

Figure 2. Did you need to fill any other professional gaps?

Hence, not surprisingly, when asked to rate the importance of different professional skills in their current jobs (Figure 3), according to the more than 50% of the respondents all professional skills were considered important, with the highest proportion given to working independently and the capacity for critical thinking. It seems highly important to "*make future engineers question their social impact on society (environmental, political and social impact of technology), via ethics and critical social sciences (as opposed to management or mainstream economy)*" (4206, Needs), as well as to have "*soft skills and interdisciplinary work could be introduced into the curriculum*" (4068, Needs).

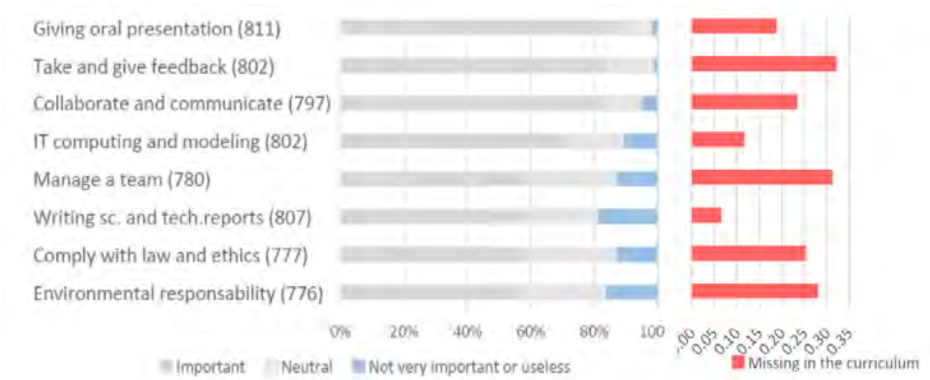

Figure 3: How would you rate the importance of the following skills in your current job?

Finally, in terms of balancing the pedagogical activities in order to better prepare students for the demands of work, the opinion of the alumni is that there should be more project management, integrated project units, interdisciplinary components, task management and more contact with the alumni. All these items were mentioned in more than 50% of the respondent population.

CDIO-inspired framework: Alumni of 2014-2019 and Alumni of 1980-2013

Alumni of 2014-2019 were asked three open-ended questions, about the strengths and needs of the programmes they finished, and an open comment as to why they would recommend the institution forward.

The textual answers (n=281) on strengths and needs were coded and analysed inductively, and as such, the most used codes included real-life/work (n=80), autonomy (n=70) and interdisciplinarity (n=59). These outcomes correspond to the quantitative ones, as they give more illustrations of struggles, for instance, "*lack of experience was a pain when trying to find a first job for me and many other students. Need more practical experience*" (220, Needs). Even in the fields where alumni work in predominantly theoretical fields, there are notions that "*for my field (academic research in mathematics): too much emphasis on purely technical aspects of the notions presented in courses, and maybe not enough emphasis on ideas/motivations*" (374, Needs). These results really talk about the more "human" aspect of the educational experience. Given that engineering careers can widely differ and alumni might take very different parts, it seems important to give a more prominent role to transversal skills, as in the case where "*my studies do not match what I am doing. The most important criteria that apply for me now would be: oral skills, quick learning/proficiency in any field, and good analysis skills*" (601, Needs).

Finally, we discussed our coding patterns and analysed it against a CDIO framework (Crawley et al., 2007) which led to the CDIO-inspired scheme that was used on the "older" alumni of 1980-2013. After categorising the outcomes, we developed a visual chart of skills the alumni would suggest students take time to develop.

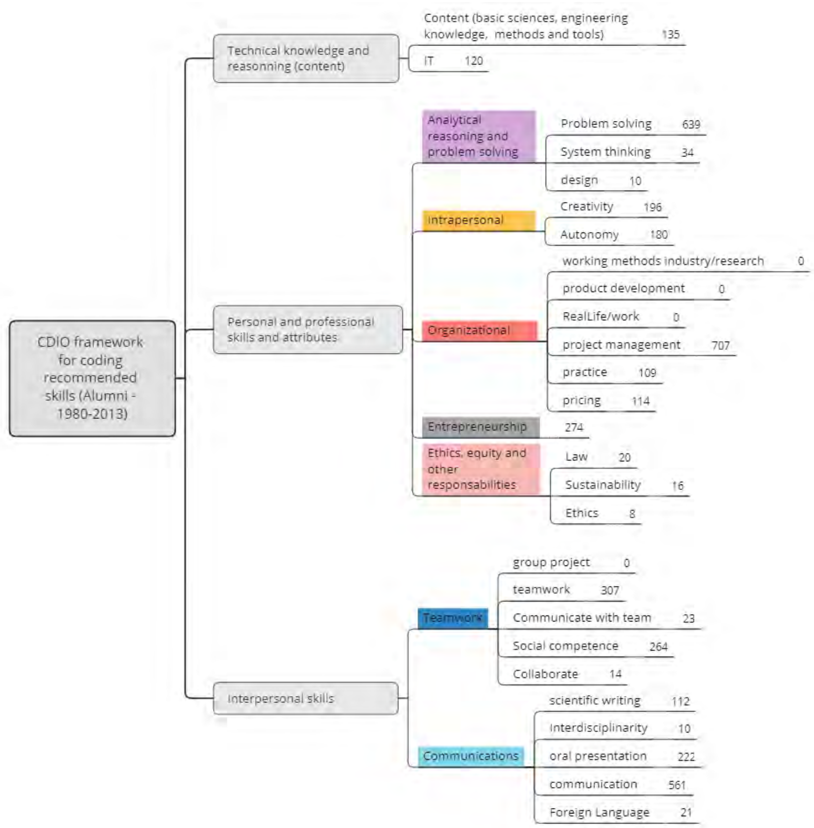

Figure 4. Alumni of 1980-2013: categorised skills alumni recommend to be developed

In Figure 4 we represent a blend of two approaches, the CDIO framework that we experimented with in our coding and our institutional approach to framing a competence model. While inspired by CDIO as a tool to analyse data, we wanted to react to our own limitation that as an institution EPFL has not been using CDIO in the courses and programmes offered.

CONCLUSION

In this paper we targeted a discussion around engineering graduates, trying to understand better what competencies could help better transition between academia and industry, as well as what would make future engineers feel competent to address current and future societal and environmental issues through their work.

We maintain our agreement with previous advocates for alumni studies about the value and necessity of regular and continuous research and inclusion of alumni in educational revision and programme development. As pointed out in our literature framework, this is a work that needs to reflect a careful exploration of the appropriate competence model(s) and comprehensive discussions with all education stakeholders.

From our results, we notice that the scientific base of our educational programmes is strong, and lacks are mainly observed in aspects of transversal skills, such as those in the area of interpersonal skills and personal and professional skills and attributes. In our discussions, we further ask the question of how and where in the curriculum should the transversal skills be taught and whether all skills and competencies should be taught in classrooms by teachers, or whether there are other avenues within academia to nurture learning environments that would provide opportunities for these competences to be developed. Our question relates to the limitation of formal curriculum and scaffolding necessary for the development of the mentioned skills.

Nevertheless, while these reflection questions can sparkle future research, the current study gives us food for thought in terms of ongoing discussions on programme development and graduates' work preparedness. Particularly embedding the results of our exploratory efforts in using a framework such as CDIO into our local context was a useful activity to gauge where our capacities and shortcomings are. The exercise of this character provides a potential for our own institution in its efforts to advance the continuous review and development of a competence framework for engineering education.

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THE NATURE OF PROGRESSION BETWEEN YEARLY PROJECT COURSES

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KTH Royal Institute of Technology

ABSTRACT

This study focuses on the *progression* between courses in a programme, meaning that the learning experiences build upon and reinforce the previous ones. The idea of mutually supporting courses is a cornerstone of *the integrated curriculum*, and hence of the CDIO approach. However, despite much use of the term, there is a lack of work to conceptualise progression. The aim of this paper is, accordingly, to provide a richer theoretical conceptualisation of progression and to apply this in analysing the implementation in a programme. In this case, we focus specifically on the progression through a series of courses based on authentic engineering projects. Such courses, called Design-implement Experiences, are a prominent feature of the CDIO framework; Standard 5 recommends at least two project courses with progression through the curriculum. The context for the study is the 5-year Electrical Engineering programme at KTH Royal Institute of Technology. It contains a series of yearly project courses starting in the first year and ending with the master thesis project. The purpose is to support students to synthesise and consolidate their learning in previous and parallel subject courses, and to develop professional engineering skills. Here, the progression between the three first project courses is described with detailed elaboration of three themes: communication, project planning and management, and ethics. The questions guiding our investigation are: What is the nature of progression across these project courses? In particular, along what dimensions is progression planned, and how is that implemented in the course design?

KEYWORDS

Progression, curriculum, learning sequence, project-based learning, assessment, electrical engineering, Standards: 1, 2, 3, 4, 5, 7, 8, 11, 12

INTRODUCTION

To support engineering students in developing the competences necessary for life and working life, the CDIO approach implies that the engineering curriculum should address both the deep working understanding of disciplinary fundamentals, as well as professional skills, approaches and judgement. The curriculum is made up by subject courses, dominated by the logic of disciplines, and project-based courses that provide a context in which students can work in the logic of problems (Edström & Kolmos, 2014). Within the CDIO community, the engineering project courses are called Design-Implement (or Design-Build) Experiences. They are authentic learning experiences giving students opportunities to consolidate and apply their conceptual understanding and develop professional competences.

A fundamental idea of the CDIO curriculum is that courses should be *mutually supporting*, meaning that we strive to create synergy between the curriculum elements. This means that connections between courses are made explicit so that learning becomes more meaningful, and that learning experiences build upon each other so that student competence progressively increases over time. Such synergy should be sought between subject courses, between subject and project courses, and between project courses. There is a temporal dimension in that students experience the connections as they go through the educational programme. Connections can be made over short time, such as between parallel courses, or they can be more longitudinal, even across years. Connections can be directed backwards, refreshing or taking advantage of previous learning, but also forwards, signalling how and when the next steps will be taken.

The aim of this paper is to consider what progression is conceptually and illustrate how this can be implemented in a programme. The context for the study is the 5-year Electrical Engineering (EE) program at KTH Royal Institute of Technology. Over the years, this program has been iteratively developed using the CDIO approach, with the explicit aim to create a coherent program with a progression of project-based and hands-on learning experiences. The latest remake, which we focus on here, came about to address longstanding problems with recruitment and poor throughput. The idea was to empower students and support their professional identity formation. In short, the program should not just support the students in *learning about technology*, but also in *becoming engineers*. A programme-driven course development approach was used, meaning that the ensuing course design was driven by the needs of the programme and its students. This study focuses on a series of project courses, one in each of the first three years. The courses support students to synthesise and consolidate their learning in previous and parallel subject courses, and the project courses are also coordinated between themselves to create progression regarding students' development of professional skills. We use our new elaborated understanding of progression to analyse this sequence of courses.

Two questions guide our investigation: *What is the nature of progression across these project courses? In particular, along what dimensions is progression planned, and how is that implemented in the course design?*

The paper is structured as follows. In the next section, we seek and review previous conceptualisations of progression, within the CDIO literature and in the general educational literature. Then follows a description of the EE programme and its sequence of project courses, with a more detailed view on how three major professional engineering skills are taught with progression across the courses. These are communication, project planning and management, and ethics. Finally, we analyse the progression exemplified by these "strands" using our new theoretical lens.

CONCEPTUALISING PROGRESSION – LITERATURE REVIEW

Progression in the CDIO Literature

Progression has from the outset been a central idea in the CDIO approach. It is implied in various ways, though sometimes indirectly and by using other terminology. An early example is when Malmqvist et al. (2006:2-3) mention "*the planned learning sequences for learning outcomes that are developed through integrated learning experiences throughout the* *curriculum*" and "*development routes for knowledge and skills that are taught in a number of consecutive courses*".

CDIO Standard 3 calls for a curriculum designed with *mutually supporting disciplinary courses*. The CDIO book elaborates: "*The curriculum is coordinated, with mutually supporting elements, each taking on a well-defined function. The elements work together to enable students to reach program learning outcomes*" (Crawley et al., 2014:86). The authors further suggest mapping program goals with courses, "*assuring that no program goal is neglected and that there is a deliberate learning progression in the program*" (Crawley et al., 2014:89). The idea is to productively coordinate the design of learning experiences across the curriculum: "*Sequence is the order in which student learning progresses. If sequence is properly developed, learning follows a pattern in which one experience builds upon and reinforces the previous ones*" (Crawley et al., 2014:104).

The term progression is used in numerous CDIO works. A well-documented example of program development with deliberate progression across the curriculum can be found in the integration of sustainability in the Mechanical Engineering programme at Chalmers (Enelund et al., 2013). Another example is the *Electronic Engineering Ladder* at NTNU, consisting of four tightly coordinated courses (Lundheim et al., 2016). Here, to support students' development of communication skills, the teachers deliberately keep some aspects *constant* across courses, e.g., the same teaching team, while they introduce *variation* in others, e.g., professors give feedback in the first semester and in the second students give feedback in peer review (Larsen et al., 2016). In another case, Spooner et al. (2008) describe a series of project courses: "*The yearly projects confront students with different forms of teamwork in an intense but gradual, dynamic but controlled experiential process*". Citing the spiral curriculum model, Yang et al. (2021) present an educational program designed "*to support the levelling up of knowledge and skills from one semester to another, from one module to another*".

We note that the focus in the CDIO literature is typically on practical curriculum development while efforts for more elaborate conceptualisation are limited (see also Edström, 2020). For instance, Gunnarsson et al. (2009) found different underpinning views on progression when comparing the CDIO implementation at Linköping University (LiU) and the Technical University of Denmark (DTU). Both universities had mapped the high-level program goals with courses, to show what each course contributed to the program as a whole. Interestingly, they had operationalised these connections differently. The method at LiU was to characterise the learning activities used in the courses to address each goal (introduce, teach, utilize), but at DTU they classified the relevant course learning outcomes according to Bloom's taxonomy. The authors noted the difference but refrained from analysing it further, taking a more practical and descriptive approach:

> "*Characterizing and quantifying knowledge and skills is a complex task with many dimensions and, to the best of our knowledge, there is no universal and generally accepted way of dealing with this task. The aim of this part of the paper is to present and discuss the approaches that have been used […], rather than discussing this vast topic in general*" (Gunnarsson et al., 2009:9).

This paper is an attempt to make inroads into this vast topic. The next step is therefore to consult the general literature about progression.

Disambiguation of the term

As we trace the conceptualisation of progression in the educational literature, we see that the term is used in three ways, so there is a need for disambiguation. The first meaning refers to the *students' progression through the education*, either across stages, for instance how many continue from secondary school to engineering programs, or within a program, for instance how many students continue to the second year. Progression is then used as a synonym of retention, i.e., as the opposite of drop-out.

The second use of the term refers to the learner's development or maturity. *Learning progressions* are "*descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another*" (National Research Council, 2007, p. 214). There are many frameworks to measure, or assess, student learning. Often, the quality of learning is operationalised in a *taxonomy*, an instrument to classify student learning. Perhaps most familiar are Bloom's taxonomy (for a useful overview, see Krathwohl, 2002) and the SOLO taxonomy (Biggs & Collis, 1982). In CDIO literature also the Feisel-Schmitz taxonomy has been used (Crawley et al., 2014:152). What is often lacking in the literature on learning progression, however, is the discussion of the educational experiences. Student development is studied on its own, independent from how they learned or how the curriculum is designed. There is little focus on why students are at a certain level of understanding, or how the educational outcome could be improved. One exception is when Brabrand and Dahl (2009) map the intended learning outcomes to a taxonomy to obtain the average levels addressed in different stages of a degree program.

The third meaning of progression takes a teaching perspective and focuses on how to support the students in their learning progression, through curriculum design and teaching. This is the *planned progression across the curriculum*. As seen above, this is the meaning of the term that has been central to CDIO, and which we focus on in this paper. Guided by their intentions as to what the students should learn, teachers plan and coordinate sequences of learning experiences in the programme, to support students in achieving increasingly advanced learning outcomes in appropriate stages. There are however different views regarding how to sequence learning over time. Traditionally, engineering education has leaned towards a *deductive* approach meaning that all new theoretical knowledge must first be introduced to the students before they are given the opportunity to apply it. Conversely, an *inductive* approach means that students are first exposed to application helping them discover what they need to know. New knowledge is presented after the students have understood the need for it. This can be seen as a more student-centred approach. Inductive instruction encompasses many different teaching methods, such as problem- and project-based learning, inquiry learning, and just-in-time teaching (Prince and Felder, 2006).

Progression as a Spiral Curriculum

Models of curriculum design have been suggested to promote student's progressive learning. Bruner presented the idea of a *spiral curriculum* based on the notion that every subject consists of core ideas. The curriculum "*should revisit these basic ideas repeatedly, building upon them until the student has grasped the full formal apparatus that goes with them*." (Bruner, 1960, p. 13). Hence, the spiral curriculum does not simply repeat the topics being taught, but deepens them, with new learning building on the previous and as a result the students' competence increases. Harden and Stamper (1999) point out that the value of a spiral curriculum lies in reinforcement, a move from simple to complex, integration, logical sequence, higher level objectives and flexibility.

Much of Bruner's inspiration stemmed from science and mathematics education (Bruner, 1960), however, it has been successfully implemented also in other fields such as medical education (Harden & Stamper, 1999). It has also been used in vocational training as a method of incorporating theoretical aspects of the training into more practical job-oriented areas while iteratively deepening the students' knowledge and skills (Dowding, 1993).

The spiral curriculum has also been proposed for engineering education. Clark et al. (2000) applied the model in conjunction with problem-based learning in engineering education to prepare students for "*demanding careers that not only require technical competence in an engineering discipline but also require communication, teamwork, and life-long learning skills*" (Clark et al., 2000, p. 222). Sheppard et al. (2009) suggest that the curriculum should take students "*on a trajectory from novice to competent performance as practitioners*". They describe how instructors should gradually increase the complexity of the problems and their contexts, until similar to actual professional practice. They state: "*This process should happen both in individual courses and over a program*" (p.26). However, they leave it to educators to spell out any implications.

In the context of medical education, Harden (2007) emphasises the multidimensional nature of progression and suggests a model with four dimensions of progression. *Increased breadth* implies that the student can extend their mastery of a specific learning outcome to new topics or different contexts, whereas *increased difficulty* instead focuses on the depth of knowledge or difficulty of skill. The third dimension, *increased utility and application to practice*, focuses on the transition from theoretical understanding to practical application. The fourth dimension, *increased proficiency*, represents areas in which the student shows more efficient performance such as being better organised, being more confident, taking less time to complete a task, making fewer errors, etc.

PROGRESSION IN THE ELECTRICAL ENGINEERING PROGRAMME AT KTH

Background – the Programme

The Electrical Engineering (EE) programme at KTH is an integrated 5-year Bachelor and Master, see Figure 1. It has a long history as a traditional, course-oriented program with a solid theoretical foundation. After many years of poor recruitment and throughput, the programme was redesigned using the CDIO approach to increase attractiveness and motivation for the students.

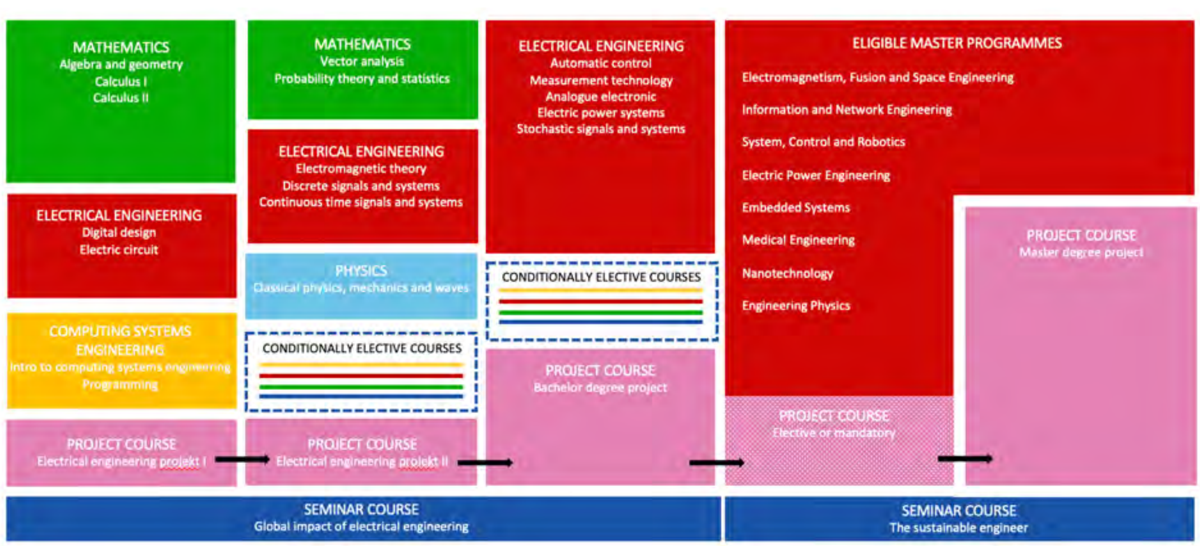

Figure 1. Program design, Electrical Engineering at KTH.

To coordinate the courses and ensure progression in terms of the technical content, four teacher teams were formed, in *Electronics*, *Signals and systems*, *Electromagnetics*, and *Programming and computer engineering*. To strengthen students' development of professional engineering skills, a sequence of practical experiential learning experiences was implemented. Each year contained a project course based on design-build challenges, designed to strengthen the program profile and connect with the subject courses.

In this paper, we focus on the project courses in each of the first three years (Bachelor level), ranging from 6 to 15 ECTS credits. Their current design was made around 2012 (for descriptions of earlier versions, see Lilliesköld & Östlund, 2008; Bengtsson et al., 2008). On the master level, students have at least one more project course and an individual thesis project (30 ECTS) for the degree of Master of Science in Engineering.

In the following we will first give an overview of the three project courses. Thereafter we turn to a thematic description of the progression across the courses for three selected aspects.

A Series of Connected Courses

Year 1 and Electrical Engineering Project I (7,5 ECTS)

Just like in most EE programs, the first year includes basic mathematics, electrical engineering (electric circuits & digital design) and computer engineering (programming and computer systems engineering). The project course, *Electrical Engineering Project I*, is designed to tie the first-year courses together with emphasis on *Design* and *Build*. Inspired by Simone Giertz and her "Shitty Robots" (Giertz, 2018), students are given the challenge to build a robot. With an Arduino board as the brain, the robot should interact with the physical world and solve a problem in everyday life. Apart from that, there are no requirements on the robot. Inspired by the iterative process structure of design thinking (Dym et al., 2005), students present and get feedback on two or three rapid prototypes in an early assessment activity. They are then encouraged to review and improve their overall design ideas before starting to build. The robot task makes students draw on knowledge and skills from the courses in programming, electric circuit, digital design, and computer systems. The role of the teachers is to provide *process support* rather than cover any new technical content.

Year 2 and Electrical Engineering Project II (6 ECTS)

In the second year, students go deeper into mathematics and EE courses, including vector analysis, statistics, electromagnetic field theory, physics, signals and systems. This provides the basis for the second-year project course, which can therefore have a much more technical focus. Now, students work more independently and there is only one lecture to introduce this year's challenge; all other teaching is in the form of supervision sessions. The course follows a full Conceive – Design – Implement – Operate structure, driven by its assignments. The first is a requirement specification (*Conceive*) including how the requirements can be tested, with a rough timeline and resource plan as appendix. Next assignment is the system design (*Design*), where the students present their solution, from input to output. A delimitation in this course is that the students cannot use premade parts. If they need a coil, they must buy the copper wire, and design and produce the coil themselves. The same goes for any system parts. After the Design is approved, the students start building it (*Implement*). The building phase ends with a demo day, where all students and faculty are invited to view the students' different solutions to the challenges. Once the solution is demonstrated, the students continue with measuring their solution and make a gap analysis on their design vs the actual working product (*Operate*). This analysis is then presented in the project report.

Year 3 and the Bachelor Thesis Project (15 ECTS)

The bachelor thesis project is carried out in groups of two. The challenges vary from typical design-build projects to more theoretical challenges within the research projects of the faculty. The project is part of a context, that addresses some type of challenge in society, and contain 3-6 subprojects under each context. Hence, the pairs belong to a larger “context group”. For instance, context can be The Smart Home, and subprojects can be optical detection of a person falling, heat regulation, or security of IOT devices. A challenge can be to hack the camera of a robot vacuum cleaner or an alarm camera.

Progression Across the Project Courses

We will now zoom in on the progression between the three courses along three strands: *Communication*, *Project planning and management*, and *Ethics*. We note that a drawback of this thematic narrative is that it understates the natural interplay of the themes within each course. Focusing on the three courses also fails to demonstrate how other courses in the programme contributes to the themes. For instance, the responsibility for teaching ethics and societal impact is shared between these project courses and the longitudinal seminar course Global Impact of Electrical Engineering (see Figure 1).

Progression in Communication

In the first-year's project course, learning to communicate is more important than the actual technical outcome of the project (the robot as such). This is reflected in the learning objectives and the assessment where the quality of the robot determines only a small part of the grade. Students get to practice several different types of communication that they could expect to meet in an industrial development project and recognise the importance of adjusting both tone and content to the purpose and target audience in each particular case. For instance, they describe and discuss the project with stakeholders without too much technical detail. Students write a project plan, status reports and a “lessons learned” report. In the end of the course, they summarize the technical outcome and learnings from the project in a technical report. Each individual student writes a peer review of the technical report of another group (hence each group gets several reviews on their report). They present the project orally with other engineers as target audience, and they demonstrate their robots to a mixed audience in a public robot exhibition. The assessment also includes making a YouTube video that shows the purpose and functionality of the robot to the general public. These are premiered in a mini film festival – complete with a popcorn machine.

In the second-year project course, students communicate through a number of reports or demonstrations. They make a requirement specification, preliminary design, poster presentation, technical report and an individual peer review. These reports are now far more technical in character as they draw on much deeper and broader technical knowledge. Students also present their design in a seminar, and their final solution and poster at a fair.

Many communication aspects of the bachelor thesis mirror those that are practiced in research. One is the context summary, with a section on ethics and a popular science summary for the public. Final reports are formatted as scientific papers, using an IEEE journal template, and presentations are organised like a one-day scientific conference with opposition. Each student also writes a peer review. Mirroring academic aspects is not only appropriate to satisfy some of the learning objectives for the degree – it also seems to increase the enthusiasm among faculty for supervising and assessing the bachelor thesis.

Across this sequence of courses, the training in communication is managed through a long line of reports in a great variation of formats. Students get feedback – and a second chance to address the feedback. This structure helps the student to learn, since they need to address the given feedback. Oral presentation is the exception as there is no second chance, however they start presenting in year one, and there are several opportunities. The students thus get an extensive training in most means of communication.

Progression in Project Planning and Management

The role of the first-year course is to train the students for future projects and all other courses. Therefore, they learn and practice project planning and management tools far beyond what they need in this particular project. Basic project management is addressed in lectures and the course book *Handbook for small projects* (Eriksson & Lillieskõld, 2005). A large share of the assessment focuses on project management, with the deliverables following the methodology in the handbook. Each hand-in is graded within a week, and students get a second chance to improve their work. One important topic is resource planning. Students are allowed to spend 160 hours each (corresponding to the course credits). They are asked to hand in a work breakdown schedule (WBS), time plan (milestone chart) and a resource plan visualizing all planned hours. The project plan also includes goals, responsibilities, project model, risk analysis and a communication plan. In the brief status report, they update the time plan and the resource plan and address the current status of the project. The project management assignments end with a final report focusing on the lessons learned, but also follow up the goals from the project plan. The main focus here is on what insights they will bring to future project courses.

In the second-year project course the students can instead structure the project the way they want and then evaluate. No project plan (etc) is required. Nonetheless, they must hand in a requirement specification with a strong emphasis on the goals and how to measure these goals, an important dimension in any project plan. We only ask for a high-level timeline, for the students to see key deadlines. The group still needs to keep track of the time used and report every week, retrospectively. This is to avoid them working excessive hours, and to monitor whether they need more support in their projects.

In the bachelor thesis project, we raise the requirements on being able to choose appropriate project management methods, and on being proactive. Students are not required to follow any specific method like in the first year, nor are they free as in the second year – however they are required to choose their method, either a traditional or an agile approach. There is a seminar to support the students in their choice, and an optional feedback session where groups present their plans to the teachers and other student groups. This is to support students to learn from seeing how other groups are managing their projects, whether using traditional or agile methods. The groups that choose a traditional method are required to formulate highly developed *SMART* goals, that is, Specific, Measurable, Achievable, Relevant, and Time-bound (Eriksson & Lillieskõld, 2005). They also make a WBS of the thesis work as in previous courses, however the requirements on the risk analysis are increased both in scope and in the identification of proactive and reactive actions. Finally, we ask for a project model that will give them early warnings if they start to fall behind or procrastinate. The plan is followed up by two status reports, but a final report is optional. If students choose a more agile approach, requirements are the same, but the structure becomes different. While many students choose a traditional approach, it is often with such short iterations that it could be characterised as a mixed approach.

With this sequence across the three years, we have seen good development and the quality of many project plans in the third year is very high. If we force students to follow a fully developed project planning and management structure in the first year, they are very free in the second year, and in the third year they take responsibility for choosing and proactively implementing an appropriate structure. Their experience of both the mandatory approach and the freedom is intended to afford them useful insights for the third-year thesis project.

Progression in Ethics

The first-year project course features a guest lecture on ethics in engineering. In relation to this we also have a discussion on whether there are any ethical considerations the students must consider when developing their robot, but there is no assignment.

In the second year, this is followed up by a role-play on ethics. It is designed as a hearing, where a company wants to introduce an electronic system to position kids in day care. Students play different roles to bring about various perspectives, as experts, teachers, teenagers, parents, lawyers or people who have been abused. The role play ends with a presentation on different concepts to make ethical considerations and a discussion on what responsibility we have as engineers.

The bachelor project contains a half-day workshop on ethics, followed up by an assignment where the students write an analysis on the ethical impact on the thesis work and the technology that the thesis addressed.

We find that ethics can really engage students and generate many relevant discussions. It is however important to introduce and integrate these aspects thoughtfully. Students will have difficulties making the connections if ethics it introduced in an overly philosophical or abstract way, and they will immediately see through if something is just an add-on. It is important that each course handles the topic well so that students are not demotivated for it when they encounter it in the next course. When ethics is addressed from an engineering perspective, and especially when integrated in the design-build courses, it is a topic that engage and can help to open the students' minds.

ANALYSING THE PROGRESSION

To analyse the progression across the course sequence, we draw on Harden's dimensions (2007), summarized in Table 1.

Table 1. Dimensions of Progression (based on Harden, 2007).

Dimensions of progression	**Explanations**
Increased breadth	Broadened competency of a specific learning outcome by extending it to new topics or contexts. Existing skills and knowledge are accommodated with new ones.

Increased difficulty	More in-depth or advanced consideration of a specific learning outcome or application to more complex situations.
Increased utility and application	Transition from a more theoretical understanding to practical application to start integrating into the role of an engineer.
Increased proficiency	More efficient performance e.g., being more organised and confident, needing less time on tasks and producing fewer errors etc. The student also needs less supervision and is able to take more initiative and defend their actions.

In *Communication*, the *increased breadth* is perhaps the most emphasised dimension of progression, as the courses aim to prepare students for an extremely wide variety of communication formats, from simple and playful presentations over many professional forms of reporting and finally scientific communication. The *increased difficulty* is seen first in year 2 when *what* they communicate becomes much more advanced, whereas the increased difficulty in year 3 lies in both more advanced *content* and more advanced communication *format*. We cannot say that there is *increased utility and application* but that is just because it is fully implemented already from year 1. The *increased proficiency* comes with the multitude of opportunities for practice, and the great variation of communication tasks.

The progression in *Project Planning and Management* is less linear. While they start in the first year with full *breadth* and *difficulty*, this is instead pared down to a minimum in year 2. There is strong *increased utility and application* in year 3 when students have to customize the project model for their own needs and context. Throughout all these experiences students are required to show *increased proficiency*.

The progression in *Ethics* can be seen in the *increased breadth* in year 2 when they get to imagine multiple perspectives as well as the *increased proficiency* as they get to actively participate. Year 3 sees *increased utility and application*, as they analyze ethical issues in their own particular project and wider in the context.

CONCLUSIONS

Final Reflections

This paper described how progression is implemented in different ways across the Electrical Engineering curriculum, with some examples that are perhaps a little counterintuitive. It is important to note that the conceptual analysis of the case presented here is retrospective. The progression between the courses emerged pragmatically and organically, rather than being theory driven. The design of progression was still intentional, however much of the resulting course design was shaped by the teachers' interest, and also constrained by practicalities, resources and available space in the curriculum.

The collegial discussions before, during, and still continuing after the remodelling of the programme, show that teachers have different ideas about progression and how it should be implemented. There is, for instance, constant tensions about whether the instructions should be deductive or inductive. The teaching culture in traditional programs like Electrical Engineering tends to lean towards a deductive view on knowledge, and hence learning and teaching. This also represents what the teachers have experienced themselves as students and in most of their academic career. The series of project courses can be seen precisely as a platform to introduce more inductive elements into the curriculum, which is otherwise basically deductively organised with the basic courses early in the curriculum. As we could see above, the projects draw on students' increasing breadth and depth of theoretical knowledge from the subject courses they have taken. Hence, the setup also draws on the advantages of a deductive approach.

Future work

This description and analysis of progression refers to the *planned progression across the curriculum*, meaning that the focus is on teachers' intentions with regards to student learning and the subsequent curriculum and course design. As we have also shown, another important meaning of progression refers to students' development. However, studying the extent to which the actual student learning follows this trajectory would be a future study. Further analysis of the whole EE programme is also warranted, focusing on progression with regard to the technical subject content, the use of mathematics, and other aspects not covered here.

The theoretical contribution of this paper serves as a starting point in our work to create a conceptual framework for progression in higher education. The framework should be useful not only for retrospective analysis, but also to guide curriculum and course development.

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SKILLS ASSESSMENT IN INNOVATION AND ENTREPRENEURSHIP EDUCATION INITIATIVES

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ABSTRACT

Skills assessment is a topic within experiential learning teaching pedagogy, such as challenge-based learning (CBL), which calls for attention. Most university teachers know how to assess and judge the knowledge levels of their engineering students but need to learn more about assessing the so-called 21st-century skills (e.g., leadership, problem-solving, empathy, communication) and how the assessment influences the learning process. Therefore, this paper aims to study the connections between the learning process and skills assessment in innovation and entrepreneurship education (I&E) initiatives and discuss how to assess student's skills in a transparent and safe way. To achieve that scope, we compare and critically discuss four I&E education experiences from the University of Trento (Italy) and Linköping University (Sweden), considering different variables such as learning goals, contents, team formation, teamwork, and expected outcomes. We identify four main findings: (i) facilitation and coaching are an essential ingredient in the courses, (ii) development-oriented feedback from teachers helps students to acquire new knowledge and improve their skills, (iii) formative assessment - both informal and formal - through matrices can help teachers in measuring progressions and difficulties in individual students, (iv) ENTRECOMP framework can support the soft skills evaluation. In conclusion, we underline the importance of assessing skills on two levels (the individual and the team) through recognized and well-described tools. Secondly, personalized self-directed learning tools, such as structured learning reflection and tailor-made learning criteria, are also beneficial but have limitations. Finally, formative assessment matrices, with defined requirements for different levels, also seem helpful.

KEYWORDS

Innovation and Entrepreneurship Education, 21st-century skills, Self-directed Learning, Formative and Summative Assessment, Challenge-based Learning, Standards: 1, 2, 7, 8, 9, 10, 11

INTRODUCTION

Skills assessment is a topic within experiential learning teaching pedagogies, such as challenge-based learning (CBL), which calls for attention. Most university teachers know how to assess and judge the knowledge levels of their engineering students. Still, they are less knowledgeable about assessing 21st-century skills (González-Pérez, & Ramírez-Montoya, 2022). Hence, they need "educational models and formal and informal educational practices that scale the development of 21st-century competencies" (ibid p. 26). According to Geisinger (2016), 21st-century skills can be (i) cognitive, (ii) technical, (iii) interpersonal, (iv) and intra-personal. Cognitive skills include problem-solving and critical thinking, while technical skills encompass entrepreneurship and finance. Interpersonal skills include executive function and self-management; intra-personal skills encompass social skills such as communication and collaboration. As these skills are included in the learning outcomes of most engineering programs, it is crucial to find efficient ways to assess them and understand their impact on the learning process.

Over the years, our assessment instruments, particularly for knowledge assessments, have become more sophisticated. For example, the SOLO (Structure of Observed Learning Outcomes) taxonomy (Biggs & Collis, 1982) enables us to grade students' efforts. However, university education is not, as emphasized above, just about theoretical knowledge; it also involves developing skills necessary to address present and future challenges. To prepare students for the VUCA world of volatility, uncertainty, complexity, and ambiguity (Bennett & Lemoine, 2014) and enable them to be successful engineers that can engineer (Crawley & al, 2007), we need to consider the interplay between acquiring both knowledge and skills. This is especially relevant as new technologies such as AI, robotics, and complex data management are entering the scene and calling for educational innovation that matches industrial development (González-Pérez, & Ramírez-Montoya, 2022).

In this context, frameworks such as the Entrecomp (Bacigalupo & al, 2020) and EPIC (HEI Innovate initiative) are relevant. Previous research has explored the connections between challenge-based learning (CBL) and the CDIO (Conceive, Design, Implement, Operate) framework (Gunnarsson & Swartz, 2022), as well as how the project model method is used to assess CDIO skills (Svensson & Gunnarsson, 2005). The general application of assessing students' cognitive learning process using the SOLO taxonomy concerning learning outcomes (Biggs & Collis, 2014) has also been studied. However, no examination has examined how to measure and assess skills transparently and fruitfully. In order to address the lack of optimal assessment in higher education, specially dedicated to engineering education, we aim to discuss how to measure skills in a meaningful and possible way and how to treat skills obtained prior to versus within the course. Second, we elaborate on measuring the students' skills development in innovation and entrepreneurship (I&E) education initiatives such as curricular and extracurricular courses, hackathons, and challenges. Finally, we also handle the need to manage issues of objectivity of the teacher employing what affects the teacher's assessments.

Based upon the above-identified problems and research gaps, this paper aims to study the connections between the learning process and skills assessment in innovation and I&E education initiatives and discuss how to assess skills transparently and securely for the students. To reach this purpose, we will identify, test and evaluate some of the present tools for assessment. The paper is organized as follows; it starts with a theoretical background about CBL and self-assessment approaches and tools. This is followed by the research method used and the empirical setting for the study, followed by the discussion of findings and conclusions.

FRAME OF REFERENCE

Challenge-based learning

CBL is an innovative approach to education that focuses on engaging students in solving real-world problems through collaboration, critical thinking, and problem-solving skills (Observatory Tecnológico of Educational de Monterrey, 2015). The literature on CBL is growing, and in this paper, we follow the definition of Norrman et al. (2022, p. 762), where CBL is described "as an experiential learning approach that starts with wicked, open and sustainability-related real-life challenges that students, in cross-disciplinary teams, take on in their way and develop into innovative and creative solutions that are presented in open forums." Challenges are provided by companies, public institutions, associations, and communities that deal with real problems and seek sustainable solutions. This way of working strengthens not only the educational results but also the regional innovation ecosystem as it joins together all parts of the "knowledge triangle" (EIT, 2012) or the so-called quadruple helix (university, industry, government, civil society). Companies and organizations giving challenges are named challenge providers - abbreviated CPs from here on - (Norrman et al., 2022). The CBL approach is based on the idea that students are more motivated and engaged when presented with challenging and authentic problems to solve rather than being given pre-determined answers, as usual in traditional teaching.

CBL promotes student-centered learning and fosters 21st-century skills, including creativity, critical thinking, and collaboration (Thomas, 2012). CBL also requires students to apply the knowledge and skills they have previously learned, which goes well with the CDIO framework's ideas (Gunnarsson & Swartz, 2021). This "new" way of learning can be traced back to the thoughts of Dewey (1938; 1963) and is rooted in constructivism, a pedagogic theory that posits that knowledge is constructed by the learner through active engagement with the environment (Piaget, 1971; Vygotsky, 1978). This theory emphasizes the importance of student-centered learning and self-directed learning (SDL) since the role of the learner is crucial in the learning process (Jonassen, 2002). Deci and Ryan (2000) and Ryan and Deci (2000) explicitly show that motivation plays a crucial role in learning. For all these characteristics, CBL is gaining momentum at various Higher Education Institutions (HEIs) worldwide (Vignoli et al., 2021). Some of the reasons that make CBL popular are that: (1) it provides instructive and experiential learning for students who can have a bath in a real job context, (2) it delivers real solutions and outcomes that the companies can implement, (3) it revolutionize the way of teaching and the role of the teachers who become coaches and mentors, or as in ECIU named "teamchers" (Eldebo et al., 2022).

Moreover, CBL has societal impacts. Students usually work to solve real problems and are often encouraged to work with peers from different disciplines - i.e., in what is mentioned as cross-disciplinary teams (Pérez-Sánchez et al., 2020). Since students approach complex problems, the learning experience becomes multidisciplinary and includes stakeholder perspectives (Kohn Rådberg et al., 2020).

Formative VS summative assessment

Formative and summative assessment, generated from the formative and summative evaluation (Lau, 2016), is used in schools worldwide, not least within the compulsory education system. Formative assessment aims to promote student learning, which is done through feedback and clearly expressed knowledge requirements for each grade, see, e.g., the SOLO taxonomy by Biggs (2014). Feedback is essential in formative assessment as it supports cognitive and professional development (Svensäter & Rohlin, 2022). According to Hattie & Timperley (2007), effective feedback must address goals, progress, and matters for improvement. It is also essential to be aware of how and in which way we communicate and give feedback to promote the individual student's learning process. Yorke (2003) means that formative assessment can be both formal and informal - or both planned and interactive, which according to Yorke, are similar to Cowie and Bell's (1999) distinction. According to Yorke (2003), formal formative assessment (FFA) is defined as "those that take place about a specific curricular assessment framework" (p. 478).

Using frameworks as assessment matrices are expected, not least within the Swedish school system. These matrices contain activities the student must perform or knowledge requirements/criteria to achieve a specific grade. After the completed activity, the effort is assessed. The assessment of the student's activity includes feedback from which the student can learn. In this way, it is clear that FFA is connected to the student's learning process. The summative assessment focuses on measurable results, such as the number of points on a written exam or the level of a report, i.e., it measures students' knowledge by summing up the students' results of assignments and for the course as a whole. In this way, summative assessment has a clear connection to knowledge assessment. Lau (2016) points out that formative and summative assessments complement each other and must work together rather than be seen as contradictions. By combining formative and summative assessments, we achieve a blended assessment form. Svensäter & Rohlin (2022) mean that in "a blended form of assessments, formative assessment is a tool to improve students' summative performance, and formative assessment is in this way a real precursor to summative assessment" (p.150). Other concepts, such as continuous and interim assessments, are also used (Ghiatău et al., 2011) to describe formative and summative assessment mixtures.

Self-directed learning and self-assessment approach

SDL relates to the self-assessment approach, which evaluates one's performance and understanding of a task or concept (Butler & Winne, 1995). This approach is rooted in the theory of self-determination (Deci & Ryan, 2000; Ryan & Deci, 2000), which posits that individuals have innate psychological needs for autonomy, competence, and relatedness. According to this theory, when these needs are met, individuals are more motivated and engaged and perform better in their learning (Reeve, Jang, Carrell, Jeon, & Barch, 2004). Self-assessment or self-reflection is related to metacognition which refers to the awareness and regulation of one's cognitive processes (Flavell, 1979). It involves monitoring and controlling one's learning, which leads to better understanding and performance (Barkley, Cross & Major, 2014), a fact pointed out also in the pioneering works of Dewey (1938; 1963).

In CBL, as mentioned before, it is essential to stimulate 21st-century skills acquisition. The assessment of these skills is crucial, especially in I&E education initiatives (Fiet, 2001). This new learning model requires new assessment tools that monitor the soft skills acquisition process (Scroccaro & Rossi, 2022). Specifically, reflective learning tools can support this assessment by remembering acts and events, exploring why things went a certain way, and taking possible actions for different experiences. Changing the way of teaching and learning impacts the assessment, particularly on learning goals and skills assessments.

METHODOLOGY

We base our paper on our teaching practice and on a comparison between four I&E education initiatives that have been given at our universities (1) the InnoCore Challenge, (2) the AI industrial challenge, (3) the inGenious course, and (4) the Innovative entrepreneurship course. The first two initiatives were run at the University of Trento (Italy), while the third and fourth were run at Linköping University (Sweden). This article's authors managed one or several programs: Dr. Alessandra Scroccaro was part of the staff for programs (1) and (2), dr. Milena Bigatto managed the program (2), Cia Lundvall was part of the program (3), and Dr. Charlotte

Norrman was involved in courses (3) and (4). Dr. Jeanette Engzell was part of the staff for the course (4).

All these courses are challenge-based, cross-disciplinary, and offered to engineering students. The InnoCore Challenge is also addressed to biotech students. The inGenious course is open to students from all faculties and universities, although the majority applying to the course are engineering students. In these courses, we have, over the years, tested several instruments in the domain of the self-directed learning approach to assess skills such as entrepreneurial-, leadership-, project management, teamwork-, communication- and presentation skills. For programs 1 and 2, we tested the learning agreement, learning diaries, and reflection reports (Gibbs' reflective cycle). In courses 1, 2, and 4, the EPIC (Entrepreneurial Potential and Innovation Competences) tool was elaborated by the HEInnovate (EU Commission and OECD initiative) Higher Education Institutions Innovate initiative based on the ENTRECOMP (Entrepreneurial Competences). For programs 3 and 4, we tested matrixes for formative assessment and group contracts, and for reflections in course 3, we also used the so-called GROW model (Whitmore, 1994) - Goal, Reality, Options, and Will/Way forward. The following sub-paragraphs describe the abovementioned tools and our experience using them.

Learning agreements, learning diaries, and group contracts

The learning agreement is a document negotiated between the supervisors and the students to ensure that certain activities are undertaken to achieve an identified learning goal (Knowles, 1986). Students discover and partly choose their learning objectives and identify what strategies and resources they can mobilize to achieve them.

Learning diaries are one-pager reports delivered during the course to evaluate the team's quality of work and understanding of the undergoing process. Questions can include (1) What went well in the teamwork during a specific phase? (2) What did we learn as a team? (3) What to improve in your teamwork to work better together? (4) What will they put into practice? Starting from the lessons learned, teams had to identify what they would do practically to work better. Group contracts are agreements with roots in project management, following a structured form and set up by the students to regulate how they will interact throughout their project - their codes of conduct, roles, and goals. They also discuss the resources, actions, and risks of their projects.

Reflection reports

The reflection report (Gibbs, 1988) is a document that guides students through 6 stages to learn from the experience that they had just left behind them and give them a chance to put some order, identify what went well and what did not go well, and plan their following actions.

1. Description: Students have a chance to describe the challenge experience in detail—the main points to include here concern what happened.
2. Feelings and thoughts: Students explore feelings or thoughts during the course and how they may have impacted the experience.
3. Evaluation: Students evaluate what worked and what did not in the experience, trying to be as objective and honest as possible by focusing on both the positive and the negative aspects of the experience.
4. Analysis: The analysis step is where students can understand what happened by extracting meaning from it, targeting different aspects that went well or poorly, and asking themselves why.
5. Conclusions: In this section, students can conclude what happened during the challenge.

6. Action plan: Students plan for what they would do differently in a similar or related experience in the future. It can also be beneficial to think about how they will help themselves to act differently.

The EPIC tool from the ENTRECOMP framework

The EPIC course assessment tool is designed by HEI Innovate, a project made up of the European Commission's DG Education and Culture in partnership with the OECD to help educators measure the effectiveness of their entrepreneurship courses. The EPIC tool is connected with the ENTRECOMP (Bacigalupo et Al., 2020). This standard reference framework identifies 15 competencies in three key areas (Resources, Ideas, Opportunities, and Into Action) that describe what it means to be entrepreneurial. The assessment works with a set of statements across five thematic areas with which course participants can assess their development: (1) entrepreneurial competencies, (2) entrepreneurial intentions and attitudes, (3) enterprising behaviors, (4) entrepreneurial strategies, and (5) educational effects. The EPIC tool is a self-assessment tool through which students can assess their level of entrepreneurial competencies at the beginning and the end of the I&E course. Thus, this tool is part of the SDL tools. Following Geisinger's (2016) view of skills and skills assessment, we can conclude that tools such as ENTRECOMP could be a good instrument for measuring skills development.

THE EMPIRICAL CASES

The following sub-paragraphs describe the four I&E education initiatives we have compared.

The InnoCore Challenge (University of Trento)

The InnoCore challenge is an online and in-presence I&E education initiative created by the University and Trento and HIT (Hub Innovazione Trentino Fondazione) that took place in 2022. The challenge is part of a European project (Erasmus +). The project is driven by five other European partners from the academy and business world to shape qualified professionals on cutting-edge enabling technologies and innovation management for Biotech Core Facilities. The 25 European participants (Ph.D. and Master students) with biotech backgrounds were divided into five teams and asked to find and present, through a 7-minutes pitch, sustainable solutions for five companies.
In the first few days of the challenge, students were asked to fill in the Initial EPIC questionnaire and an individual learning agreement to identify the main learning goals, activities, and strategies and evaluate their achievement. During the challenge, teams had to monitor their progress and teamwork through learning diaries and focus on what went well (strength points of their teamwork), what did they learn, what should be improved (weak points of their teamwork), and what they would take into practice (strategies to improve actions for the next steps). After the experience, individuals had to fill in again the Final-EPIC questionnaire and a final reflection report. As the InnoCore challenge is an extracurricular initiative, all the deliverables and the final pitches are not graded.

The AI Industrial Challenge (University of Trento)

The "Industrial AI Industrial Challenge" is an open innovation contest organized by the Department of Information Engineering and Computer Science of the University of Trento and HIT. In its first edition, the Industrial AI Industrial Challenge was held online from September until December 2021; students, researchers, industry experts, and experts from regional start-ups worked together to improve the companies' industrial processes thanks to the adoption of artificial intelligence techniques. The teams committed to solving the challenges proposed by nine selected companies by analysing large datasets and creating algorithms and predictive models based on machine learning methods. Challenges regarded the workforce planning's optimization, predictive maintenance, quality control, logistics, and supply chains in various industries, such as manufacturing, production, and distribution of electricity, pharmaceutics, food, and water treatment.

While for most students, the challenge was an extracurricular activity, though assigning three additional ECTS (European Credit Transfer and Accumulation System), two teams of students completed the challenge in the context of a master course they were attending (AI for Innovation), though receiving additional support from university professors. Altogether, the initiative involved 45 students from four different departments, 25 professionals from the 9 selected and participating companies, and nine mentors from nine AI start-ups from the region. Students had to fill in a final individual reflection report. As the challenge is an extracurricular initiative, all the deliverables and the final pitches are not graded.

The inGenious Course (Linköping University)

The inGenious course (799G52) is a challenge-driven cross-disciplinary project course, given in cooperation between Linköping University and Almi East Sweden AB. The pedagogy used in this course is CBL. Cross-disciplinary work and communication are a vital part of the course and are practiced in the group work process. Examinations are done by written reports and reflections and oral presentations in case of" pitches" in open forums. The challenges are connected to the UN SDGs and come from companies, organizations, and the public sector in the region.

The course acts as a "bridge" between students and the trade and industry and promotes the CPs' sustainability development. In addition, students can apply their theoretical knowledge practically and gain experience in a challenging and complex process. Students gain essential skills by reflecting on the group processes and group dynamics in collaboration with other professions, reflecting on the work process from different perspectives such as business, sustainability, and ethics. The course's activities could include writing a group contract, the "Shitty Prototyping" serious play, a seminar on pitch technique, training workshops (including Value Creation Forum), pitch occasions, and a workshop on responsible innovation. The students are facilitated throughout the course. The course is designed so that the students can contribute with their knowledge and competencies, which they take into their projects, but also provides new knowledge. At the end of the course, the students write a thorough individual learning reflection where they reflect upon the course purpose and learning goals and use the GROW model to identify what and how they have learned.

The "Innovative Entrepreneurship" Course (Linköping University)

The overall purpose of the course "Innovative Entrepreneurship" (TEIO06) is for students to acquire knowledge and abilities within the general areas of I&E, focusing on business planning for new, innovative ventures. The course is at an advanced level. The pedagogical approach used in the course is CBL, following the approach of ECIU. The course starts with an "Idea jam" presenting open challenges connected to the UN SDGs. During this jam, students are engaged by external speakers representing the CPs (e.g., organizations, firms, or ventures/projects). Individually, they choose a challenge and form groups during the seminar. During the course, they gather information about their challenges to identify business opportunities that imply a commercial solution. Finally, they concretize and describe their business idea in a business plan. Throughout the course, the students are supported with theoretical lectures giving them tools for investigating and analyzing the idea. Examinations are in case of a couple of reflections and a group work report. A couple of pitching occasions and creative workshops focusing on skills are included in the latter. Grades are failed, 3, 4, and 5, where 3 implies pass, and 5 is the highest grade. Skills-related parts, including a learning reflection, are graded pass/fail based on participation. Although this course aims to give the students both knowledge and skills, only knowledge is assessed and graded. Hence, better tools for skills assessment would help improve the examination.

DISCUSSION AND FINDINGS

Table 1 below compares and summarizes at the same time the four initiatives mentioned above through criteria such as syllabuses issues and CDIO framework.

Table 1. A comparison of the four I&E Education initiatives

Course	**AI Industrial Challenge**	**InnoCore Challenge**	**InGenious**	**Innovative entrepreneurship**
Learning goals	Analysis of large datasets, creation of algorithms and predictive models	Personal goals, Teamwork, Communication	Skills and knowledge-oriented goals	Skills and knowledge-oriented goals
Challenge Contents	Industrial processes, thanks to AI	Core facilities, knowledge transfer, project writing and management, communication	Challenges relating to the UN SDGs (above all, SDG 11)	Create business models that solve challenges related to UN SDGs
Credits and duration	9 ECTS 4 months	6 ECTS 4 months	8 ECTS 4 months	6 ECTS 2 months
Team formation and teamwork	45 students 9 teams Cross-disciplinary	25 students 5 teams Cross-disciplinary	15-40 students per semester, 2-8 teams Cross-disciplinary	75-110 students, 16-20 teams Cross-disciplinary
External collaborations and challenge providers	9 companies 9 Mentors from local start-ups	5 companies 2 mentors in each team, and corporate tutors	2-8 companies, public bodies, and NGOs	Research groups, companies, municipalities, or regional actors
Expected outcomes	Challenge solutions presentation in front of a jury with companies	Challenge solutions presentation in front of a jury with companies	Challenge solutions described in reports and presented in an open forum	Challenge solutions described in business plan format and oral presentations in open forums
Type of assessment	Formative and Summative	Formative and Summative	Formative and Summative	Formative and Summative
Skills assessment and Assessment tools	Self-reflection approach; Reflection reports; Final project	Self-reflection approach; Learning agreement; diaries; EPIC survey; Final project	Self-reflection approach; Group contract, project plan, final report, individual reflection paper	Self-reflection approach, literature review, and business plan report
CDIO framework	Conceive, design, and implement	Conceive, design, and implement	Conceive, design, and implement	Conceive, design, and implement

The following considerations are the outcome of two analysis levels. The first comes from analysing all data collected through the tools presented in the Methodology section. We considered the written answers given by students, as individuals or as a group, to the tools provided, such as the learning agreement, the learning diaries, the reflection reports, and the formative matrices. The second one comes from Table 1 and compares the four educational initiatives. We have found that the AI Industrial challenge students have learning goals that are more quantitative-oriented compared with the other I&E education initiatives. However, competencies such as workforce planning, predictive maintenance, quality control, logistics, and supply chains were also part of the challenge, which are also related to skills and knowledge. Not surprisingly, most learning goals focused on skills and knowledge-oriented goals but with different contents and contexts of their challenges. The AI Industrial Challenge content focused more on industrial processes/collaboration than InnoCore, which fosters knowledge and technology transfer in the project partner national ecosystems and supports the development of the local economy. Comparing the two other courses, inGenious and Innovative Entrepreneurship, they aim to work with challenges relating to the UN SDGs but also incorporate external CPs such as the region, the municipalities, research groups, and private actors (ventures and firms) from trade and industry. All the courses combine theory and practice as they use the challenges to create a real-life context for learning. The time frame is critical since it facilitates more time for the learning and reflection process. Students are more likely to incorporate new knowledge and experience and to reflect on their process, but the issue of assessing the students is the same.

However, comparing the student groups in the different initiatives, we have experienced differences regarding the number of students involved in each initiative. The largest student group, 75-110 students, is in the Innovative Entrepreneurship course. The number of students/participants in the teams care similar, about 4-6 participants per group. The context and CPs differ between the four initiatives. The AI Industrial Challenge, InnoCore Challenge, and inGenious course rely on their external collaborations, mainly with companies and additional mentors. The Innovative Entrepreneurship course, instead, has many different collaboration partners such as research groups, companies, municipalities, or regional actors. In the case of Innocore Challenge, one of the five companies, as a follow-up, signed a contract with one of the universities and involved one of the Ph.D. students in the result's exploitation. In the inGenious course, all CPs and all students sign contracts with Almi East Sweden AB. The CPs also have the opportunity to buy back what the students have developed, and in such cases, Almi East Sweden AB acts as an intermediary.

In the Innovative entrepreneurship course, no contracts are written, and the CPs' engagement differs from high to modest engagement based on the individual preferences of the CPs. Projects of the AI Industrial Challenge and InnoCore challenge are presented as final projects through an oral pitch in front of a jury. Professors and companies make the jury. The examination of the project report for both inGenious and Innovative entrepreneurship is both presented in reports and presented in open forums. In the Swedish courses, the students present in open forums, on an open stage in inGenious, and at a mini trade fair in the Innovative Entrepreneurship course. In all courses, all initiatives are assessed in both a formative and summative way. All have the self-reflection approach with varying aspects, such as learning agreements, diaries and surveys, and group contracts. Comparing these four initiatives helps to understand the differences and similarities between I&E education initiatives, and we came out with four main findings. Below we present the main findings justified through citations extracted from students' feedback, reflection reports, and matrices.

Finding 1. The Role of Facilitation and Coaching in I&E education initiatives

"I also enjoyed the individual pitch training […]. Moreover, getting feedback from [the facilitators] who have watched many people pitch felt luxurious. I thought it was a productive session where I got to try different ways of pitching, see how others pitch, and learn more about what suits me best." (from a reflection report in the inGenious course 2022). The first finding is that facilitation and coaching are essential ingredients in the courses, which correlates with the findings on feedback in previous research (Hattie & Timperley, 2007; Svensäter & Rohlin, 2022). Facilitation (e.g., teachers or teamchers giving feedback, peer feedback, external mentors evaluations) or the so-called mentorship can be seen as a formative assessment in the future. Mentors or teamchers can ask questions that make them "find their way" or the correct answer when facilitating the students. The facilitation also allows them to reflect upon their learning process. As a facilitator, the teacher sees the learning process. Based on a matrix or model, the facilitator should be able to follow and document the individual student's (or group's) progress and development. This would be a type of informal formative assessment that could be interesting to explore further.

Finding 2. Feedback from teachers in I&E education initiatives

"We consider that our teacher's involvement in directing us towards outside sources of information was of consequence to our learning outcomes since we recognize that the lack of this would have limited our ability to reproduce the same level of performance in our project work." (from reflection report in Innovative entrepreneurship). The second finding is that a teacher's development-oriented feedback and response (e.g., the formative approach) will help the student gain new knowledge and skills and grow. That this is important for the students has become apparent when reading their learning reflections. That is why it is essential to pay attention to the manner through which the teacher/teamcher gives a response. Teamcher as a facilitator should focus more on how students can develop, explain and add, not on what is wrong, what students have failed, and what is missing.

Finding 3. Matrices for measuring progressions and difficulties

Assessment matrices help the student clarify how they are assessed. "If you know what to do, it reduces the stress of what to deliver. I think it is a splendid example of how a course should convey what is important to learn." (from a student in Innovative Entrepreneurship). The third finding is that informal and formal formative assessment through matrices can help teachers measure progressions and difficulties in individual students. Matrices are also helpful for the students, as shown by the citation above, as they show what is expected to be obtained. Hence they are a complementary tool that can help teamwork during the course and guide teachers to refine their way of teaching in similar courses. Matrices can make transparent both the students' difficulties and weaknesses and their substantial factors, which, taken together, can affect the learning experience and the achievement of the learning outcomes. However, matrices could also entail drawbacks. One student in the innovative entrepreneurship course posed this as follows; "it [the matrice] might be a problem since it can make the studies be based purely on passing the assignments and not to learn the content of the course." (from a student in Innovative Entrepreneurship). The conclusion is that matrices are helpful, but it must be made clear that formative assessment tools are, on the first hand, guides for improvement - not lists of minimal viable achievements to pass, even though some are regarded as such.

Finding 4. EPIC from ENTRECOMP as a reference for entrepreneurial skills evaluation

The fourth finding is that the EPIC tool and ENTRECOMP framework are valuable for international comparative studies in this field. The EPIC tool created for its measurement allows us to collect valuable data to analyse over time and space the effectiveness of measures to develop one of the skills identified by the European Commission as crucial for the future. In addition, through the full implementation of that tool in two courses (the AI Industrial Challenge and the InnoCore Challenge) and an ongoing attempt in a third course (Innovative Entrepreneurship), we have identified the efficacy and consistency of this instrument for the I&E education initiatives. This tool can support the evaluation of students' soft skills' progression, even if it does not necessarily support summative assessment. For both courses where full implementation was done, we encountered that students improved their entrepreneurial skills by comparing the initial and final evaluations. EPIC tool evaluates three areas of entrepreneurial skills. On average, 65% of applicants perceived a progression in skills of ENTRECOMP Ideas and opportunities area, such as identifying opportunities for innovative value creation, anticipating which opportunities will be of high value, selecting the most valuable opportunity when faced with multiple options, coming up with innovative ideas or find new ways of solving problems, assess the social and ecological impact of their ideas. On average, 80% of applicants perceived a progression in skills of ENTRECOMP Resources area, such as achieving goals and performing unfamiliar tasks, finishing started tasks despite setbacks and failures, actively networking in order to increase the number and quality of contacts, finding the right people, estimate a budget for a new project, read and interpret financial statements, make people enthusiastic about ideas, convince others to engage in your activities. On average, 70% of applicants perceived a progression in skills of ENTRECOMP Into Action, such as being the one who takes the initiative, make difficult decisions, quickly assess complex situations, create a project plan, organize and structure tasks in a project, set project goals, deal with uncertainty when implementing new activities, work under stress and pressure, actively participate in teamwork, promote ideas and opinions when working in a group, look for new opportunities to develop new knowledge and skills, learn from challenging tasks.

CONCLUSIONS

This paper aims to study the connections between the learning process and skills assessment in I&E education initiatives and discuss how to promptly and securely assess students' skills. We also aimed to identify, test and evaluate some of the present tools for assessment. As mentioned above, CBL is an SDL approach. Learners learn, set goals, identify resources, and evaluate their progress (Knowles, 1975). Students become co-responsible for their learning processes and outcomes (Mercer-Mapstone et Al., 2017) and are invited to co-design and evaluate their experience. This approach is disruptive from what they were used to because it denied top-down teaching and learning and proposed a proactive involvement from them.

SDL focuses on motivation and favors a self-centered and reflective approach since students can evaluate the quality of their work, measure their performance with their learning goals, identify the strengths and weaknesses of their work, and plan for iterations and improvements. If students take charge of their learning, the teacher or teamcher has to help them improve by showing what can be developed and how - i.e., pursue guidance and criteria for what is needed for each grade and how the students can improve. In that sense, formative assessment is vital, which focuses on the learning process and motivates students to perform. We have found that skills assessment was essential but tough to handle in practice, especially when balancing the assessment between the team- and individual levels.

In the courses mentioned above, we have tested several tools. The conclusions from these tests are the following: First, assessing skills through recognized and well-described tools is urgent as this implies transparency and legal security. If this is omitted, there is a risk that the assessments are made on subjective grounds. A recent study by Mehic (2022) showed that this could happen. Although criticized, it showed a correlation between facial attractiveness and grades which is highly unwanted in education contexts. Secondly, personalized self-directed learning tools, such as structured learning reflection and tailor-made learning criteria, are also beneficial but have limitations. Finally, formative assessment matrices, with defined requirements for different levels, are also helpful but have the potential for improvements.

FURTHER RESEARCH

The Entrecomp framework has proven to be efficient. However, more comprehensive implementation and analysis are needed to reach its full potential. Hence it is essential to implement it also in more extensive courses. Another critical task that calls for further investigation and development is, as highlighted by, e.g., González-Pérez, & Ramírez-Montoya (2022), to consider the technology development of industry 4.0 and 5.0 (see, e.g., Zambon et al. 2019) and match this with education efforts that match industrial development. Working in such a way enables engineers to also engineer in the future, which is the mantra of the CDIO (see, e.g., Crawley et al. 2007).

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TEACHING ENGINEERING AS A DESIGN SCIENCE

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ABSTRACT

In this paper, we take the position that teaching engineering itself is a design science. Engineering educators worldwide creatively design, implement, and evaluate new ways of teaching to facilitate the learning of their students and to respond to various societal challenges. Sadly, their teaching and course design discoveries often remain with them. By representing successful experiences in engineering education as structured pedagogical patterns, we could develop this vital professional knowledge collectively into a so-called *pattern language*. The pattern language method acknowledges the complexity of instructional design and divides it into smaller and more understandable pieces. One piece is called a 'pattern'. This paper aims to set the argument of why and how to develop a pedagogical pattern language for engaging and activating engineering education. In Delft, we see this pedagogical language as a part of TU Delft's so-called ecosystem approach toward learning and teaching. TU Delft recognizes the need among students for impact-driven education that matches the way this generation learns and what our society needs. Successful ecosystem pedagogies will be the core of the intended pedagogical pattern language. It is our idea to develop this pattern language in close cooperation with the teaching communities of TU Delft, that is the TUD Teaching Academy, the 4TU Centre of Engineering Education, and CDIO.

KEYWORDS

engaging engineering pedagogy, eco-systems communities for teachers, pattern language, scholarship of teaching and learning, Standards: 8, 9, 10

MOTIVATION FOR A SHARED PEDAGOGICAL LANGUAGE FOR ENGINEERING EDUCATORS

Today's and tomorrow's global socio-technical challenges ask for many new ideas, sustainable solutions, and smart transition strategies. The world is particularly looking at engineers who should play an important role in 'solving' these challenges. And those technological solutions need to be seen in the context of global limits, moral decision-making, societal and environmental justice, (inter)national legal procedures, and (local) political forces. Engineers will need to be able to adapt to those changing societal contexts to stay valuable professionals over time (Moravec, 2013).

The future generations of engineers need to be guided into this complex society. That is why university teachers should look at education (and their teaching in particular) from a societal perspective, get out of their bubbles regularly by connecting with colleagues and industry, and share and discuss teaching practices and experiences. Besides, the changing world has an enormous impact on engineering pedagogies. Teaching engineering is no longer 'simply' about passing on technical knowledge from lecturer or professor to student, or 'just' doing a project to apply technical knowledge and gain more engineering skills, experience, or expertise. Education of today is also – and more and more – about higher-order and transversal skills and critical thinking in order to better understand the world, develop a professional position, and intervene in reality.

Engineering educators at universities have to cope with and teach in that fast- and ever-changing, complex environment (Kamp, 2016; 2020; Kavanagh, 2019). Accordingly, learning about engineering does not only mean learning technology fundamentals and more specialized engineering skills, but also learning to adapt to this changing and uncertain society in an entrepreneurial, responsible, and healthy way (4TU.CEE, 2021). And more and more, engineering students not only want to learn about engineering, but also want to engage with and have a positive impact in society during their studies (Dierckx, Zaman, & Hannes, 2022; Sociologie magazine, 2022; Loosbroek, 2021).

In this paper, we take the position that teaching engineering itself is a design science. Engineering educators face the challenge of developing pedagogical formats. So, every day, colleagues worldwide creatively design, implement, and evaluate new activating and engaging ways of teaching to facilitate the learning of their students. Sadly, their teaching and course design discoveries often remain with themselves (and their students), or at best within their local, departmental environment. By representing and communicating successful experiences in activating and engaging engineering education as structured *pedagogical patterns*, we could develop this vital professional knowledge collectively into a so-called *pedagogical pattern language* (Laurillard, 2012; Bergin et al., 2012; Bennedsen, 2006; Sharp, Manns & Eckstein, 2003). This can lead to more understanding and internalisation among teachers, allowing education to adapt more quickly to change and thus better match society's and students' needs and expectations.

A pattern language is – by nature – open-ended and dynamic (Rooij & Dorst, 2020). In due time, new patterns can be added to and outdated patterns could be removed from the language. A pattern language can be adjusted (and re-published) anytime. In this way, a pattern language is an invitation to educators all over the world to translate their teaching experiences into one or more pedagogical patterns and integrate them into the language. In each pattern description, credits are given to the original authors as "the origin or provenance of a pedagogical pattern is as important as citations are in research" (Mor & Winters, 2007). It is our position that twenty-first-century engineering education needs university teachers who work collaboratively to design effective, relevant, up-to-date, agile, challenging, and innovative teaching formats.

GOAL AND STRUCTURE OF THE PAPER

This paper aims to set the argument of why and how to develop a pedagogical pattern language for engaging and activating engineering education. The argument is supported by (the review of) a variety of literature with pedagogical, design, and societal perspectives. The paper can also be read as a kind of research proposal, as it presents our motivation, ambition, intended outcomes, and action plan for the coming years.

We will organize our thinking into five additional sections. First, we will deepen the teaching-engineering-as-a-design-science thinking, Then, we look at some important lessons for instructional design from more traditional fields of design. Thirdly, we elaborate on the value of pedagogical patterns for engineering education/educators and we present and argue what a pedagogical pattern could look like. Fourth, we explore in what ways we could organize and structure this potentially endless set of patterns in a coherent, accessible, and communicative way. Fifth, we will present our view on how to co-create this pattern language with engineering educators from all over the world; in particular, in cooperation with our communities at TU Delft and with CDIO.

TEACHING AS A DESIGN SCIENCE

Designing is at the core of what educators do[1]. Akker (2013) presents the elements that educators have to integrate into their instructional design in the format of his 'curriculum design spider web' (Figure 1). Together they cover a full spectrum of contents, pedagogy/didactics, and organization. However, the spider web does not say much about *how* to do the instructional design; that is the design approach or design process.

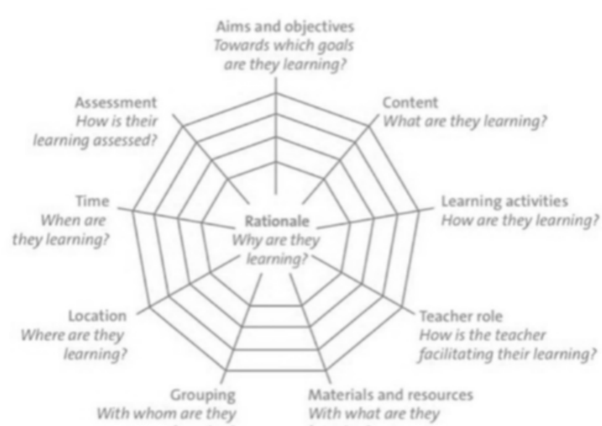


Figure 1. Curriculum Design Spider Web (Akker, 2013)

[1] Here we use the word 'educator' for both 'university teachers' and 'education coordinators'. University teachers are academic staff members, like lecturers and (assist./assoc./full) professors, with teaching responsibilities. Education coordinators are academic staff members, like lecturers and (assist./assoc./full) professors, program directors, and (vice-)deans of education, with coordination and/or leadership responsibilities such as course, program(s), or department coordination.

We distinguish here three main levels at which instructional design activities take place:

- program/curriculum level;
- subject/course/module level;
- classroom/session level.

At the **program/curriculum level,** an instructional design needs to be made for the full program, e.g. a bachelor of science undergraduate program, or a master of science graduate program. Usually, programs at universities are 1-5 years programs and they are developed in interaction with the teacher and student communities; sometimes even together with other institutes and/or industry. At this level, we consider what kind of engineer we are educating (e.g. the technical domain) and how the educational environment, including the role of the teacher, can support the professional and personal development of the student.

At the **subject/course/module level,** educators (or teaching teams) design the set-up of one 'unit' within a program/curriculum: a subject/course/module with its constructive alignment of learning contents & objectives, learning & teaching activities, and assessment strategy. An important instructional design challenge here is to make the subject/course not only coherent in itself, but also within the learning trajectory of students; e.g. taking into account prerequisite knowledge and follow-up subjects/courses. Courses very often last a few weeks or months (quarter, trimester, semester).

At the **classroom/session level,** teachers design the teaching approach for one 'lesson'. An important instructional design challenge here is the very concrete organization and planning of the session, teaching & learning activities, interaction formats (student-teacher, student-students), feedback approaches et cetera. The duration of a classroom/session 'normally' is about 1 to 4 hours.

LEARNING FROM DESIGN FOR DESIGN

It is interesting to bring into play here how design fields with a long design tradition, such as architecture, urban design, and product design, view this question of how to design and how to become a better, more professional designer. These fields developed a rich body of writings about it, from which we will emphasize 'just' two: Lawson & Dorst (2009) *Design Expertise* and Dooren (2020) *Anchoring the design process*. Lawson and Dorst (2009) make clear that there is not a single overarching definition of such a thing that we call design, as it is and/or can be…:

…**a mixture of creativity and analysis**: 'When steeped deeply in your design activity you just keep switching between analysis and creativity, between 'problem' and 'solution' without any effort.' (p. 30)

…**problem-solving**: 'pose – search – generate – evaluate – choose' (p. 30)

…**learning**: 'As a designer, you gradually gather knowledge about the nature of the design problem and the best route to take towards a design solution…' '…You propose, experiment, and learn…' (p. 32)

…**evolution**: 'A creative event occurs as the moment of insight at which a problem-solution pair comes together.' (p. 38)

…**the creation of solutionS to problemS**: important when talking about 'underdetermined' and 'overdetermined' design problems (p. 42), that is with (too) few requirements, constraints, and/or starting points, or (too) many.

…**integrating into a coherent whole**: 'Well integrated and coherent designs are characteristically simple, elegant and give the feeling that everything (RR: important) has

> been taken into consideration, and is as it should be. There is a glimpse of perfection in an integrated design.' (p. 44)

Additionally, Lawson and Dorst (p. 98-99) point out (based on Dreyfus, 2003) that design expertise is something that grows over the years of doing design, getting more experience and proficiency, and being a reflective practitioner. In brief, **beginners** tend to follow certain rules. The **advanced beginner** is much more context-sensitive. The **competent performer** has learned to develop and use certain design strategies. **Proficiency and expertise** are achieved when the performer automatically and immediately follows an appropriate design approach. And the **master and visionary** designers even go beyond. Masters display a deeper involvement in the field and visionaries consciously strive to extend the domain of operation of that design field.

From a pedagogical point of view on design teaching and learning, Dooren (2020) presents five generic elements via which the essential basic designerly skills are described. These elements are not meant as a formula for a good design or a good design process. Rather, they are anchor points to express the designerly ways of reasoning.

Experimenting, exploring, reflecting, and deciding: designers have ideas, evaluate them ex-ante, improve them, implement, evaluate ex-post, and improve again. Instructional designers have a reflective attitude toward their teaching ideas, exploration process, and instructional design decisions.

Bringing focus: during the design process, designers tend to look for and find the essence of their design that guides them, their ideas, and the sub-solutions; the educational vision behind the concrete design.

Working within domains: each design discipline has its domains. In instructional design, the domains relate to contents (learning and teaching vision, learning objectives and contents, sources and materials), pedagogy (learning and teaching activities, roles of teachers, assessment strategy), and organization (group approaches, learning environment, time). Decisions in one domain usually have consequences for other domains.

Using references: design ideas can come to the mind of the designer in many ways; for example by talking to people such as students, teaching staff, education management, learning developers, etc). Designers tend to learn and take a lot of inspiration from references, cases, and other concrete examples. They explore proven design principles and see if it makes sense to adapt them to their context.

Speaking the language of design: designers imagine possible, desirable futures and they communicate accordingly. Seeing opportunities and defining ambitions is their first nature as well as representing these via drawings, schemes and other visual strategies besides using words.

THE VALUE AND LOOKS OF A PEDAGOGICAL PATTERN[2]

Christopher Alexander recognized the complexity and dynamic quality of design. He developed a method to deal with this complexity; making the relation between the recurring nature of a problem and the process of designing a ‘solution’ that ‘solves’ that problem (Alexander, 1964, 1979; Alexander et al., 1977). This method acknowledges the complexity of design, and at the same time divides this reality into smaller and more understandable pieces. One piece is called a ‘pattern’. On the one hand, the pattern is underpinned by theory, while on the other hand, the pattern is discussed in pragmatic terms and societal value, and clarified with a sketch, photo, illustration, or example. In one ‘simple’ overview a pattern presents a bridge between a problem and a solution.

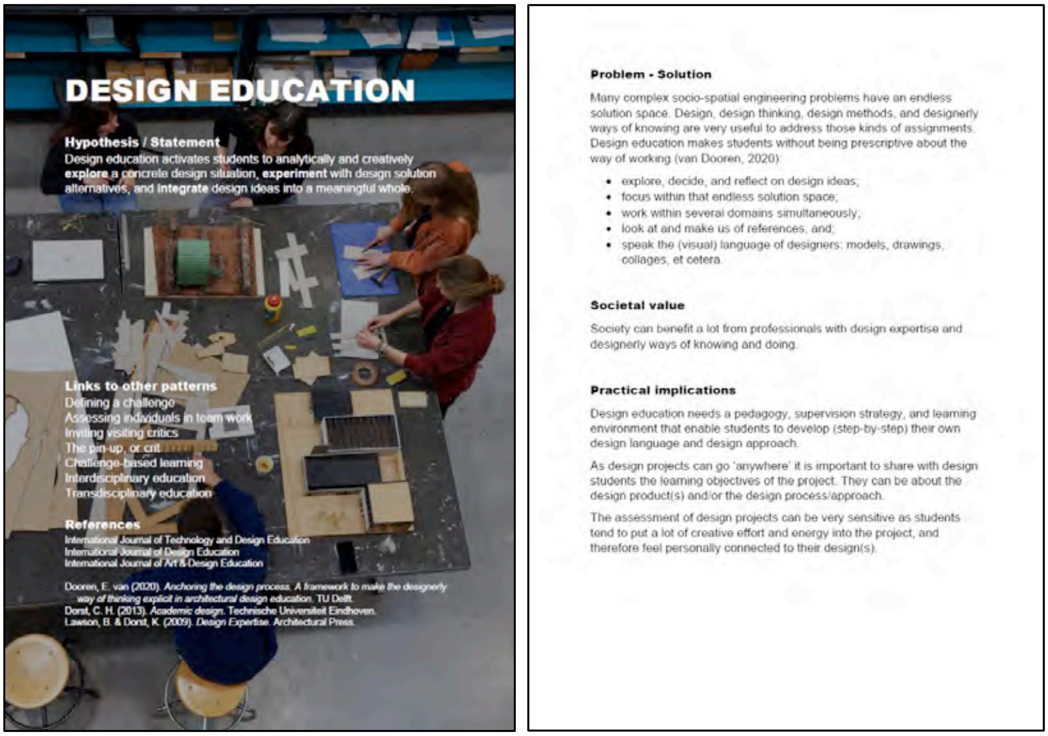
So, a pedagogical pattern bridges a pedagogical problem and a pedagogical solution. Laurillard (2012) reasons that pedagogical patterns should be made by and for the instructional design community itself, that is the educators. One can see such a building block of this pattern language as teaching or course/curriculum design principle: a pedagogical problem-solution unit. For experienced educators, (some/several) patterns might be ‘normal, ‘logic, ‘obvious’, perhaps even ‘trivial’, because they have used them so often. For those newer to teaching or newer to certain ways of teaching, the patterns offer a way for experienced teachers to pass on their pedagogical experience and knowledge (Bergin et al., 2012).

In our view, a pedagogical pattern for engaging and activating engineering education should consist of an attractive and informative title, a hypothesis on the problem-solution relation, a deeper explanation of the context of and forces behind a pattern, a theoretical backing from scientific research and literature, its societal value, its practical implications, its relations to other patterns, and one or more communicative visuals. The patterns enable constructive and solution-oriented discussions amongst the people designing or teaching a course without either bringing down the richness of a topic or losing oneself in details (Rooij & Dorst, 2020). Furthermore, the patterns are not prescriptive. The involved people, e.g. the course design team, have to decide whether or not to use (or adjust) certain patterns in their institutional context.

> *In our view, a design pattern is a semi-structured description of an expert’s method for solving a recurrent problem, which includes a description of the problem itself and the context in which the method is applicable, but does not include directives which bind the solution to unique circumstances. Design patterns have the explicit aim of externalizing knowledge to allow the accumulation and generalization of solutions and to allow all members of a community or design group to participate in discussions relating to the design.*
> From Yishay Mor & Niall Winters (2017)

Patterns can be more or less concrete and/or more or less context-specific. An example of a more generic pedagogical pattern for engaging engineering education is ‘DESIGN EDUCATION’; a more concrete one is ‘ASSESSING INDIVIDUALS IN TEAMS ’ (see Figures 2 and 3).

[2] The first part of this section is based on and partly derived from Rooij and Dorst (2020).



DESIGN EDUCATION

Hypothesis / Statement
Design education activates students to analytically and creatively **explore** a concrete design situation, **experiment** with design solution alternatives, and **integrate** design ideas into a meaningful whole.

Links to other patterns
Defining a challenge
Assessing individuals in team work
Inviting visiting critics
The pin-up, or crit
Challenge-based learning
Interdisciplinary education
Transdisciplinary education

References
International Journal of Technology and Design Education
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Problem - Solution

Many complex socio-spatial engineering problems have an endless solution space. Design, design thinking, design methods, and designerly ways of knowing are very useful to address those kinds of assignments. Design education makes students without being prescriptive about the way of working (van Dooren, 2020):

- explore, decide, and reflect on design ideas;
- focus within that endless solution space;
- work within several domains simultaneously;
- look at and make us of references, and;
- speak the (visual) language of designers: models, drawings, collages, et cetera.

Societal value

Society can benefit a lot from professionals with design expertise and designerly ways of knowing and doing.

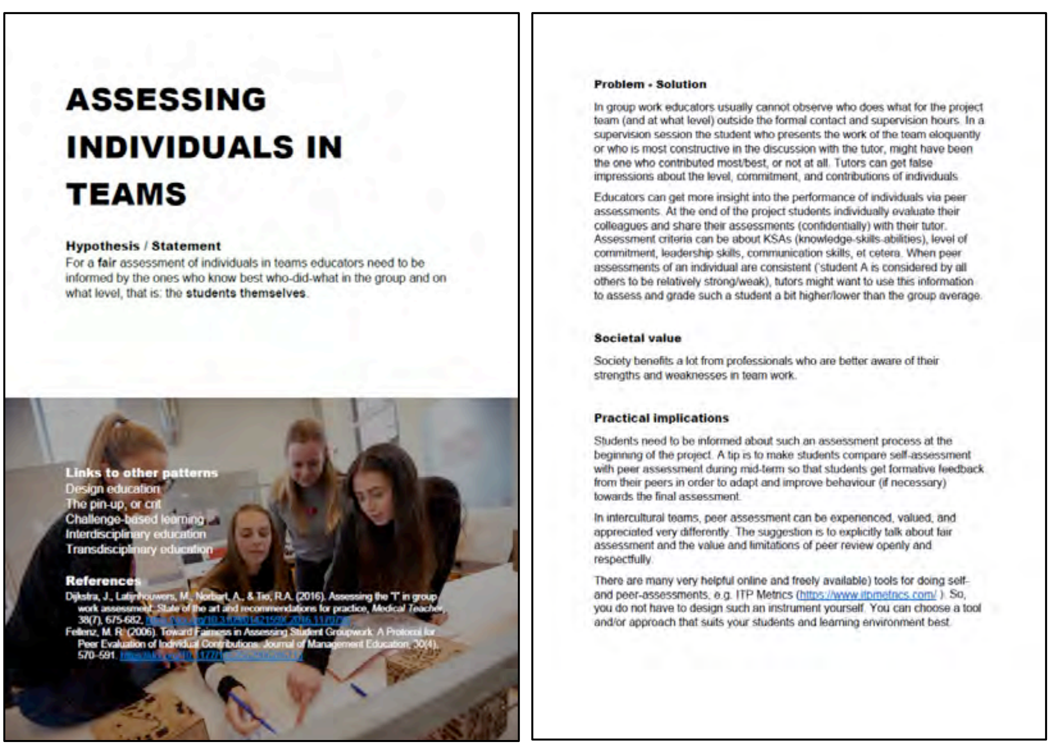
Practical implications

Design education needs a pedagogy, supervision strategy, and learning environment that enable students to develop (step-by-step) their own design language and design approach.

As design projects can go 'anywhere' it is important to share with design students the learning objectives of the project. They can be about the design product(s) and/or the design process/approach.

The assessment of design projects can be very sensitive as students tend to put a lot of creative effort and energy into the project, and therefore feel personally connected to their design(s).

Figure 2. More generic pedagogical pattern example
'DESIGN EDUCATION'



ASSESSING INDIVIDUALS IN TEAMS

Hypothesis / Statement
For a **fair** assessment of individuals in teams educators need to be informed by the ones who know best who-did-what in the group and on what level, that is: the **students themselves**.

Links to other patterns
Design education
The pin-up, or crit
Challenge-based learning
Interdisciplinary education
Transdisciplinary education

References
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Fellenz, M. R. (2006). Toward Fairness in Assessing Student Groupwork: A Protocol for Peer Evaluation of Individual Contributions. Journal of Management Education, 30(4), 570–591.

Problem - Solution

In group work educators usually cannot observe who does what for the project team (and at what level) outside the formal contact and supervision hours. In a supervision session the student who presents the work of the team eloquently or who is most constructive in the discussion with the tutor, might have been the one who contributed most/best, or not at all. Tutors can get false impressions about the level, commitment, and contributions of individuals.

Educators can get more insight into the performance of individuals via peer assessments. At the end of the project students individually evaluate their colleagues and share their assessments (confidentially) with their tutor. Assessment criteria can be about KSAs (knowledge-skills-abilities), level of commitment, leadership skills, communication skills, et cetera. When peer assessments of an individual are consistent ('student A is considered by all others to be relatively strong/weak), tutors might want to use this information to assess and grade such a student a bit higher/lower than the group average.

Societal value

Society benefits a lot from professionals who are better aware of their strengths and weaknesses in team work.

Practical implications

Students need to be informed about such an assessment process at the beginning of the project. A tip is to make students compare self-assessment with peer assessment during mid-term so that students get formative feedback from their peers in order to adapt and improve behaviour (if necessary) towards the final assessment.

In intercultural teams, peer assessment can be experienced, valued, and appreciated very differently. The suggestion is to explicitly talk about fair assessment and the value and limitations of peer review openly and respectfully.

There are many very helpful online and freely available) tools for doing self- and peer-assessments, e.g. ITP Metrics (https://www.itpmetrics.com/). So, you do not have to design such an instrument yourself. You can choose a tool and/or approach that suits your students and learning environment best.

Figure 3. More specific pedagogical pattern example
'ASSESSING INDIVIDUALS IN TEAMS'

ORGANIZING AND STRUCTURING PATTERNS

One pattern is 'simple'. Complexity kicks in if one starts relating patterns to other patterns. Pattern languages can consists of tens or hundreds of individual patterns. Every pattern usually links up to several other ones, very often in different ways (e.g., thematically, or via stakeholders). A pattern may even conflict with another pattern. If the relations between patterns are sketched out, we get a so-called 'pattern field' (Figure 4), which can easily be(come) as complex as a real design or planning assignment (Dorst, 2005).

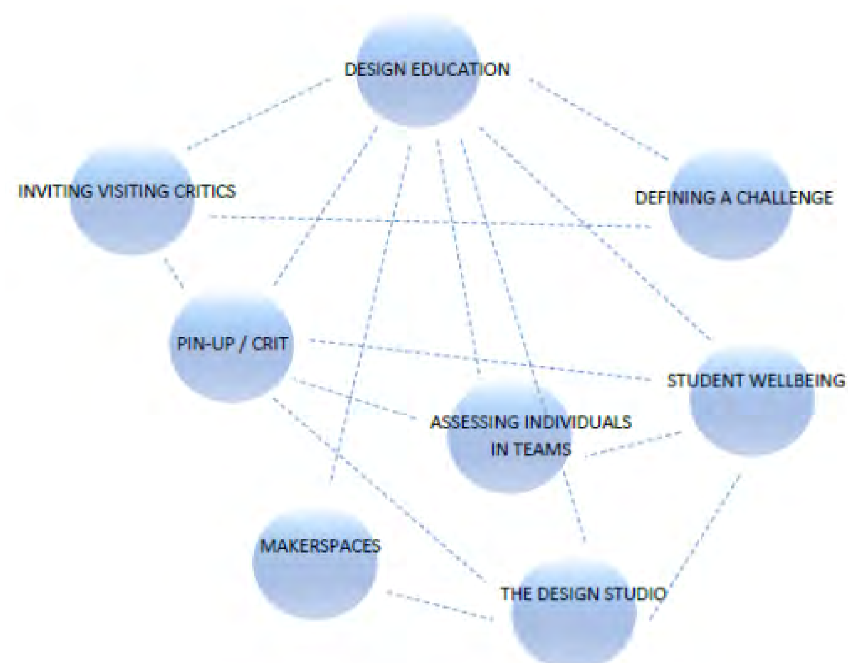

Figure 4. Example of a (relatively) small pattern field on 'DESIGN EDUCATION'

As the number of patterns in a pattern language can (drastically) grow over time, the accessibility of both the language as a whole and individual patterns become crucial. A smart way to get an overview of all patterns is by (re-)organizing them in one or more meaningful ways. Organizational principles can be:

- from abstract/generic to concrete interventions;
- from small-scale to large-scale interventions, e.g. classroom level, course level, program level;
- thematically, e.g. domains of contents, pedagogy/didactics, organization;
- from short-term to long-term interventions;
- stakeholder-oriented, e.g. individual students, student groups, partners from industry or engineering practice, lecturers, coordinators, and educational management;
- from engineering education-specific patterns to more general and holistic patterns about learning.

At the level of individual patterns, we should aim for a presentation format of a pattern that is both (visually) attractive and informative. It is our view that each pattern should contain a certain (visual) design quality itself in order to reach a large audience. So, besides clear explanatory texts and clear descriptions of examples, we should not forget to stick to a consistent structure with repeating headings and/or subtitles, but also develop an appealing sheet mirror with enough white space, and room for photos (from concrete teaching settings), schemes, or icons illustrating and emphasizing the main concepts addressed in a pattern.

Furthermore, depending on the objective of how you would like to use the patterns, certain ways of organizing and representing the pattern field might be more or less useful:

- as an **analysis** tool – to systematically analyze, review, evaluate, assess (the presence or lack of patterns in) a certain learning environment or pedagogical context;
- as a **(co-)design** tool – to catalyze the instructional design process of a course or degree program (within a teaching team) with inspiring, ‘proven’ principles;
- as a **communication** tool – to develop a shared language among various stakeholders;
- as a **co-creation** tool – to facilitate the inter- or transdisciplinary co-operation between various stakeholders;
- as a **learning** tool – to document, further develop, and share knowledge acquired. This function is not to be underestimated as society asks for continuous professional development and lifelong learning, also within universities, so also of educators.

CONCLUSIONS AND STEPS FORWARD: CO-CREATING A PATTERN LANGUAGE

This paper presents the argument why we – as engineering educators – should collectively develop a pedagogical pattern language on engaging and activating engineering education. It is our responsibility to organize future-proof engineering education and educate future-proof engineers. So, we need to not only develop but also share our insights into successful engineering pedagogies. At the same time, we understand that institutional contexts differ a lot in higher (engineering) education and nobody needs directives from others about what and how to teach. The bundling of teaching principles (the so-called pedagogical patterns) gives room to the instructional designers locally to assess if certain patterns are valuable in their local contexts.

In Delft, we see this pedagogical language as a part of TU Delft’s ecosystem-learning approach that we develop together with other learning-level institutions and various partners from within the public and private domains and civil society. In ecosystems, university and vocational education students and lecturers learn and work together with stakeholders on societal challenges. This brings interesting pedagogical insights to teachers and we see teachers learning from each other's approaches. TU Delft recognizes the need among students for impact-driven education that matches the way this generation learns and what our society needs. TU Delft promotes a distinctive approach to education that inspires students and connects our students, teachers, and researchers to the wider world: an educational and/or campus ecosystem that accelerates innovation.

Ecosystem partnerships facilitate ownership for students as they come face-to-face with the real challenges of the 21st century, apply theoretical knowledge, generate new insights, find solutions or transition strategies, and develop professional skills. As students begin to recognize the long-term value of engaging with societal partners, they can better contextualize general engineering principles. Ecosystem learning and teaching reinforce the idea that engineering students and teachers can respond directly to the actual needs of society while simultaneously accelerating innovation and change. As a result, educational quality will rise, learning with societal impact by students is stimulated, and educators become more flexible and faster (and every time better) to adapt their pedagogies. Successful ecosystem pedagogies and patterns will be the core of the intended pedagogical pattern language because they improve and refresh our teaching language continuously.

It is our idea to do all of this (and learn!) in close cooperation with the teaching communities of TU Delft, that is the TUD Teaching Academy, the 4TU Centre of Engineering Education, and CDIO. We will organize workshops in all these communities in the coming years to share views and experiences on a pedagogical pattern language. Furthermore, we will set up an ecosystem learning and teaching environment so that we can experiment with how it works and how it can accelerate innovative teaching practices. During the workshops, teaching practices of participating engineering educators are shared and 'translated' into one (or more) pedagogical patterns (to be added to our pattern language). Our intended overall outcome of this pedagogical pattern language endeavor is therefore twofold:

- An online, open-source environment that presents a pattern language for engaging and activating engineering pedagogies. Ideally, it will not only share all kinds of patterns but also tell the stories and experiences of engineering educators who made and/or used them.
- A digitally and online freely available serious card game that will help and support curriculum and course leaders, teachers, and teaching teams to playfully develop (or analyze/assess) their class, course, or curriculum design.

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BIOGRAPHICAL INFORMATION

Remon Rooij is an Associate Professor at the Department of Urbanism and TU Delft’s institutional CDIO leader. Since July 2023, Remon has been chair and scientific director of the 4TU Centre for Engineering Education, the national platform in the Netherlands that promotes innovation and pedagogical research in engineering education. Remon is a passionate lecturer, coach, course and curriculum designer, education innovator, and researcher in engineering education. Remon has over 25 years of experience in teaching and coordinating a large variety of design and planning courses and programs within the faculty of Architecture & the Built Environment. He is particularly interested in engaging engineering pedagogies that stimulate the intrinsic motivation and responsibility of students (such as design education, CBL, and inter- and transdisciplinary learning environments) and the kind of academic and professional skills that come with these. He has been in many leadership roles for the Urbanism department, the Architecture & Built Environment faculty, the TU Delft institute, and the Dutch 4TU alliance.

Linette Bossen is an Educational Advisor at the Department of Education and Student Affairs in the faculty of Mechanical, Maritime, and Materials Engineering. She engages in the development of contemporary engineering education so that engineering students can take responsibility for their learning and personal development in line with their ambition. The starting point of this approach toward engineering education is society at large with its challenges and where technological solutions no longer stand alone. Within curricula, she searches for the best-fitting learning environment supported by deploying different teacher roles. Currently, she is exploring eco-learning systems for a society where students and teachers with different learning levels work and learn together with stakeholders and citizens.

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GROUP PRACTICES IN A COLLABORATIVE DESIGN PROJECT – A VIDEO-ETHNOGRAPHIC STUDY

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ABSTRACT

CONTEXT: There is a growing interest in engineering education that the curriculum should include collaborative design projects. The problem-based and project-based learning context of this study is a design project in the fifth semester of the problem-based Architecture and Design programme at Aalborg University. The students had the task to design a real office building in collaborative groups of five to six students. PURPOSE: Collaboration and collaborative learning imply a shared activity, a shared purpose, and a mutual interdependence to achieve the intended learning outcomes. In earlier studies we have highlighted the cognitive importance of tools and the use of a wealth of bodily and material resources in students' collaborative interactional work in the design project. In this study, we focus on students' collaborative group practices in the design project. The fine-grained details of collaborative work in engineering students design projects are currently under-researched. METHODOLOGY: The preparation for an upcoming status seminar was video recorded in situ. Video ethnography, conversation analysis and embodied interaction analysis were used to explore what interactional work the student teams did and what kind of resources they used to collaborate and complete the design task. Complete six hours sessions of five groups were recorded using multiple video cameras (two to five cameras per group). OUTCOMES: The fine-grained patterns of social interaction within groups were found to be complex and dynamic. In the video recordings it was observed that students often changed constellations and break into subgroups of one, two or three students to do some work and to congregate later as a whole group. Thus, we found that the patterns of collaboration in groups practical day-to-day work were not static but displayed a myriad of different patterns. CONCLUSION: Our results challenge a naïve individual-collaborative-binary and point to the need to investigate group practices and individual and collaborative learning in design project groups and other collaborative learning environments in more detail. Physical settings in active learning environments should make fluid collaboration patterns in students' collaborative work feasible and it should be encouraged by instructors.

KEYWORDS

Design project, Collaborative learning, Group practices, Video ethnography, Standards: 5, 7, 8

INTRODUCTION

Design "constitutes the essence of engineering" according to Mitcham (1994) since an engineer is "concerned with how things *ought* to be … to *attain* goals and to *function*" (Simon, 1996, pp. 4-5). For this reason there has been a growing interest that engineering curricula should include collaborative design projects and is included in the CDIO-standards (e.g. Crawley et al., 2014; Edström & Kolmos, 2014) as engineers are expected to be able to design things and processes that can serve human needs and protect the environment. The ability to develop and design products, processes and systems and demonstrate the capacity for teamwork and collaboration have become essential requirements for an engineering degree in many countries. For example, the Swedish national university regulations require that to be awarded an engineering degree, students must "demonstrate the ability to develop and design products, processes and systems [and] demonstrate the capacity for teamwork and collaboration" (Almost similar requirements in Denmark).

Given that design-based learning activities have become a key component in engineering education, there is a need to better understand students' learning processes within design projects. Moreover, within design projects it is also important to better understand how students develop the "capacity for teamwork and collaboration".

However, collaboration and cooperation are often not always clearly distinguished. In line with (Dillenbourg, 1999), Stahl (2013, 2016), and others, we see cooperative learning as an activity there students divide up group work and then put the individual contributions together, whereas in collaborative learning students do the work together. Collaboration and collaborative learning implies a shared activity, a shared purpose, and a mutual interdependence to achieve the intended learning outcomes (Dillenbourg, 1999). Stahl (2013, 2016) argues that in studies of collaborative learning it is important to focus on small group phenomena and to use the group as a unit of analysis. According to Stahl, collaborative groups build knowledge through shared understanding, co-construction, and interaction in a joint problem space. Furthermore, he proposes that studies on teamwork and collaboration build on post-cognitive theories. Thus, a project group in a collaborative design project can be seen as a community of inquiry. Indeed, students' cognition in an engineering design project (Brereton, 2004) has been seen as an example of "distributed cognition" (e.g. Goodwin, 1995; Hutchins, 1995), since achievements do not only arise from individuals thinking, but also through collaborative thinking distributed among the members in the design team *and* from the use of epistemic tools (Goodwin, 2018).

Although collaboration is seen as an important element of design, the dominant empirical method to investigate *students'* design processes have until recently to been variants of "think-aloud" exercises with verbal-protocol-analysis (Craig, 2001) mostly with *individuals* in *artificial* settings (Bernhard et al., 2016) with tasks that were completed in rather *short time*, i.e. one to two hours (e.g. Atman et al., 2007; Atman et al., 1999; Cardella et al., 2008). More recently, studies using different forms of ethnographic methods to investigate students in naturalistic educational settings have started to appear using audio-recordings (e.g. Gilbuena et al., 2015), video-recordings (e.g. Campbell et al., 2018; Goncher & Johri, 2015), and photos and field-notes (e.g. Juhl & Lindegaard, 2013). Adams and Siddiqui (2015) describe the collection of a more extensive set of video recordings, but these are only from design-review conversations and not from the design process per se.

It has passed more than 30 years since Tang and Leifer (1991) argued for the use of video recordings and interaction analysis (Jordan & Henderson, 1995) to study group design activity. Nevertheless, there are still very few studies using interaction or conversation analysis to study engineering students group design activities in regular educational settings. To our knowledge, Campbell et al. (2018) seem to be one of the rare cases that, beside our own studies have studied engineering students' design *process* using interaction analysis.

In our own previous studies, we have made video-recordings and studied a design project in the fifth semester of the PBL-based Architecture and Design programme at Aalborg University. We found that the fifth semester students displayed epistemic fluency (Markauskaite & Goodyear, 2017) by fluent use of a rich repertoire of bodily-material resources as epistemic tools to think collaboratively in design activities (Bernhard et al., 2019). In their collaborative work and reasoning, students' employed gestures, gestured drawings, sketches drawn by hand or on an iPad, concrete models made of foam or paper, and digital 3D CAD drawings drawn on a computer, i.e. they worked both "by hand and by computer" (Bernhard et al., 2020). We also have shown how the students developed a professional dialogical practice using bodily, material and historical resources, rather than only being manifested in verbal discourse (Davidsen et al., 2020). Moreover, we have analysed and discussed the different knowledge forms embedded and emerging in students' collaborative and embodied interactions (Ryberg et al., 2020). Finally, we have used our empirical material to explore the notion of ecotones and to use post-digital theory to address problematic dichotomies such as the digital versus analogue/material (Ryberg et al., 2021).

In the literature regarding collaborative learning the *composition* of the studied collaborative group(s) is commonly static and does not change (e.g. Borgford-Parnell et al., 2013; Menekse et al., 2017). However, when analysing videos of students' interactions in our earlier studies we also noticed that students approached a particular design problem in shifting subgroups of one, two or three students or as a whole group. This implied that the collaborative group, indeed, was not static and it challenges a naïve individual-collaborative-binary. As this, to our knowledge, was not well discussed in the literature it led us to the following research question: *How could the dynamics of individual and collaborative work in students' group practices in a design project be described and visualised?*

SETTING AND METHODOLOGY

The setting of this study is the Architecture and Design (A&D) programme given within the frame of the Aalborg problem-based learning (PBL) model which was created in response to the call that engineering programmes should include collaborative design projects of varying length and complexity. The A&D programme includes elements of architecture education, but also builds on knowledge, skills, and competencies from engineering. In the Danish context this was a novel approach when the programme started in the 1990s, as traditionally the fields of architecture and engineering are separated. The creation of the A&D programme was an attempt to combine the "technical theoretical" knowledge of engineering with the "aesthetic and artistic" artisanship of architecture, to create a new interdisciplinary education.

To achieve a rich picture of students' individual and collaborative work and enabling studies to increase our understanding of engineering students' learning processes in collaborative design projects we have recorded a very large corpus of video data from A&D-students at Aalborg University in their first, fourth and fifth semesters. The interaction within groups during projects has been recorded making extensive use of the latest advances in video-technology such as multiple cameras and 360-degree cameras ("Big Video", e.g. McIlvenny

& Davidsen, 2017). Working in students' regular environments and using as unobtrusive methods for data collection as possible will help to ensure "ecological validity" and achieve an emic (participant) perspective of how students' processes of learning are played out in their regular environment in engineering design projects (Hutchins, 1995).

The data analysed in this paper is from a period 14 days into a project work where fifth semester A&D students are tasked with designing an office building for an external partner. The particular session studied is where a student group (group 3: four females, two males) is preparing to take part in a formal review session the next day. After the review session the groups have approximately four weeks left to complete their design of the building.
The interactions (Goodwin, 2018; Heath, 2016; Jordan & Henderson, 1995; Tang & Leifer, 1991) within the group were recorded using five digital camcorders (including one body-mounted GoPro camera) during the complete session. In this case the session lasted almost six hours. To facilitate analysis, recordings were synchronized.

As can be seen in the photos in Figures 1–3 the groups' workspace is encircled by a fixed wall with windows, and two "walls" consisting of whiteboards, pinboards and blackboards. One of the "board walls" is used for various design ideas and sketches with each board having a particular type or category (e.g., printed computer designs or drawings). The other board wall is used as a calendar and overview of tasks (with different colour-codings). In the midst of the group space is the "working table", which is littered with paper, sketches, laptops, models, iPads, bottles etc.

The preparation for the review session was selected for analysis as it is what Jordan and Henderson (1995) refer to as a natural unit of analysis – limited in time and with a particular purpose. As mentioned in the introduction we have previously analysed the recorded videos in regard of other research questions than is the focus in this study. In this study the focus is on students grouping practices and how they work together in different constellations. In the previous studies large parts of the verbal interactions (in Danish) have been manually transcribed by a researcher, but in this study we performed the analysis by directly "manually" viewing and analyzing students' interaction as recorded on the videos.

The videos were analyzed by primarily viewing the video from one of the cameras and coding in which constellations students worked (e.g., individually, in subgroups, or in whole group). Furthermore, students' membership in subgroups were noted, and it was noted the time constellations changed. To count as a member of a constellation a student had to actively display participation either verbally or bodily. If the coding was unsure, use was made of other videos which enabled view from a different angle. Examples of students' interactions being coded as individual work, dyads, triads, or whole group are displayed in Figures 1 – 3 and in transcripts 1 – 3 below. Although transcripts were primarily not used in our analysis, we have included them (translated into English) for illustrative purposes.

An overview of students' work in shifting constellations during the project meeting is displayed in Figure 4, with each student colour coded. Episodes of work in different constellations have been numbered sequentially. Apart from noting if students' activities were off task, the content of the interactions were not coded. Had the focus of the study been another than the present one, for example on some type of content in the interactions, the division of episodes would probably have been different.

The study was conducted under the ethical guidelines in place at Aalborg University and at Linköping University in accordance with Danish and Swedish laws. Informed consent forms were signed by each research participant. In this paper, participants have been given pseudonyms to protect their anonymity.

FINDINGS

An apparent finding viewing the video recordings is that students are, indeed, working in many different constellations during the project meeting. Before presenting and discussing the more general results in Figure 4 we will first present short extracts from students' activities as examples of individual work, work in dyads and triads, and in whole group.

Examples of different constellations

To exemplify different constellations, we have taken selected still photos from the video recordings to represent typical activities. In the pictures we have included, somewhat simplified utterances by a student and we have also included some comments. Full transcripts are also included. In the transcripts (x.y) denotes a pause in units of seconds, while (.) denotes a short pause. Double parenthesis, ((comment)), are made around comments. Symbols for prosody are not included in the transcripts and they have been translated from Danish into English. Reference to episode number is according to the numbering in Figure 4. Timing is made relative to the start of the recording of videos. It should be noted that none of the transcript display the full episode as space do not permit it.

Individual work changing into a dyad (episode 19 and 20)

In the first example we can in Figure 1a see the female students Ina, Heidi, Mette, and Sine working individually (episode 19) around the group's main table. The male students in the group, Anders and Sven, are somewhere else and their activities are therefore not recorded.

Figure 1. Episode 19 and 20 – Ina first does individual work and then calls for Mette's attention to discuss a design decision (a dyad).

Ina is trying to resolve an issue with conflicting requirements making drawings and trying things out with a Styrofoam model (Figure 1b). In turn 2 (Figure 1c) she finally calls for Mette's attention and she, still sitting on her chair, "rolls" over to Ina's place. Here we can clearly see the initiation of a dyad between Ina and Mette both by their verbal exchange and by the embodied action in form of a physical movement of Mette to Ina's place. We can also see that Heidi and Sine continue to work individually.

Transcript 1 (Related to Figure 1 – part of episodes 19 and 20. 01:03:40 – 01:11:57)

1.	Ina	((**Figures 1a – 1b.** From 01:03:40 Ina first sits silently and make drawings on her iPad, but after a while she puts it away and instead put some layers of a 3D Styrofoam model and begin to use a pencil to trace the contours of the styrofoam model onto a paper.))
2.	Ina	Mette? ((**Figure 1c.** Calls for Mettes attention at 01:11:14)) (3.2)
3.	Mette	why why
4.	Ina	this is also two hundred (.) I just started to think about it
5.	Mette	Ehmmm (9.0)
6.	Ina	Mette?
7.	Mette	yes
8.	Ina	that is because (.) I do not know if it is stupid (.) what I am doing
9.	Mette	what are you doing? (4.5) ((**Figure 1c.** Mette moves over to the position of Ina still sitting on her chair))
10.	Ina	that is because I have actually changed something in it
11.	Mette	have you changed it?
12.	Ina	it is because I think
13.	Mette	It is over here at the rear (.) because I think this that you (.) that you (.) well (.) here you get both (.) here you get both a terrace (.) but you also get a terrace here too ((**Figure 1d.** Mette has rolled over to Ina and points to the 3D-foam model))

Dyad changing into a triad (episode 22 and 23)

Figure 2. Episodes 22 and 23 – Ina and Mette (a dyad) continue their discussion from episode 20 turn to Sine (a triad) to be allowed to make adjustments.

Ina's and Mette's interaction in episode 22 is a continuation of the discussion in episode 20, but now as is displayed in Figures 2a – 2d Ina has moved over to Mette's place at the table. They make use of CAD, photos, and different gestures to discuss the issue at hand (turns 14 – 24). As a change might affect what Sine is working with, she is addressed by Ina in turn 26

(Figure 2e.). The dyad Ina-Mette is changing into a triad Ina-Mette-Sine (episode 23). Heidi is still working individually. The 10.6 s pause in line 25 should be noted.

Transcript 2 (Related to Figure 2 – part of episodes 22 and 23. 1:19:12 – 1:20:37)

14.	Ina	that is because (.) you go out right here (.) then one go around around around and in there (.) that is around (.) and then it is (.) I have tried to make a footbridge ((**Figure 2a.** As Ina is saying "go out right here, then one go around around around and in there" her index finger walks around the drawing of the building demonstrating what she means.))
15.	Mette	yes (.) and so it is too
16.	Ina	but it of course (.) requires that there is also a whole floor free outside at the walk (.) u::m
17.	Mette	yes (.) here
18.	Ina	yes (.) but it might well (.) because try not to see them here too ((Ina turns around and look at the board with the photographs.))
19.	Ina	if you say there are windows all round (.) right too ((**Figure 2b**. Ina points to a photograph while talking about "windows all round".))
20.	Ina	and then (.) if you say that there are open offices on the other side, (.) so that if that was the case (.) such that light came in gradually through the office ((**Figure 2c.** Ina illustrates with a gesture how light passes in))
21.	Mette	u::m (.) that can one certainly do (.) you can also see how narrow that passage is (.) it is right in the middle there ((**Figure 2d.** While stating how "narrow that passage is" Mette is pointing to a photograph.))
22.	Ina	well
23.	Mette	there is not very much that is there
24.	Ina	well (.) okay ((Both Mette and Ina turn to the computer again))
25.	Pause	(10.6) ((Triad starts [episode 23] after the pause))
26.	Ina	Sine, do you think it is okay for us to make some small adjustments, without ((**Figure 2e.**))
27.	Sine	yes, but I think so, but are there more details or is it just like that in general?
28.	Ina	it is only in relation to the drawing (.) it's more because we want to make it there and we're just making some changes to it
29.	Sine	yeah yeah (.) but that's what I think (.) but it's just so you don't spend time on drawings and that's really what we should be doing.
30.	Ina	yeah yeah (.) but we would like to make drawings based on it (.) so that's why
31.	Sine	well (.) it's up to you
32.	Ina	yes (.) wasn't it (.) Mette?
33.	Mette	u::m

Whole group interacting (episode 65)

Finally, in Figure 3 and transcript 3 we see an example of a whole group interaction. Mette is in Figure 3a using a 3D-foam model to present the solution they arrived at in the relation to the design issue presented above in earlier examples. Heidi comes up with a suggestion for improvement in Figure 3b that is further clarified in Figure 3d. As can be seen in transcript 3 all group members, except for Anders, is contributing to the discussion in this excerpt. However, as he is standing near Sven and Ina behind the seated Sine and Heidi, and he by his body language display that he is actively participating, we will even from this short excerpt code him as participating in a whole group constellation. Indeed, later in episode 65 he is actively verbally participating.

Transcript 3 (Related to Figure 3 – part of episode 65. 4:31:55 – 4:32:28)

34.	Mette	with a passage all way around and then ((**Figure 3a.** Mette dislocates the top floor in the 3D foam model and indicates with a hand movement the location of a passage.))
35.	Heidi	but I also think (.) what if you now (.) imagine that you are dragging that (.) then you could also imagine that you could drag the window borders in (.) well so there still is a roof sticking out that would create a possibility for some shelter ((**Figure 3b.** Heidi first points at a drawing on the iPad, then moves her hand to the 3D foam model and turns her hand to make a gesture.))
36.	Ina	yeah
37.	Sine	yeah precisely ((Mette goes to a table on the side and fetches a drawing.))
38.	Heidi	for example (if one had it here)
39.	Ina	that could also work (1.9)
40.	Heidi	yeah but ((Points to the 3D-foam model))

41.	Ina	Is it
42.	Heidi	Here (.) here is the window (.) but there is still a roof here for example and then you actually have a room up here ((Points on the 3D-foam model))
43.	Ina	yes (.) and it was actually here ((Moves closer, leans forward, and points on the 3D-foam model.))
44.	Mette	I was in some doubt what you meant (.) so with window borders on ((**Figure 3c.** Points in drawing.))
45.	Heidi	eh:: yes if one imagines something there also ((Heide points to the drawing and Sven makes a gesture with his right hand))
46.	Sven	(if) you to pull it back
47.	Ina	but you keep the shape
48.	Heidi	the window is maybe actually (0.6) here ((**Figure 3d.** Makes a gesture in relation to the 3D-foam model.))

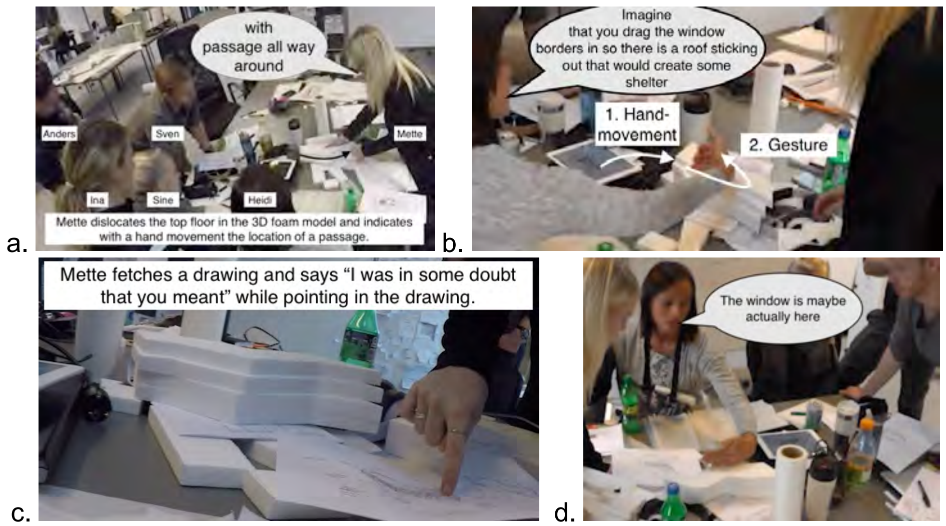

Figure 3. Episode 65 – whole group design discussion using iPad, 3D foam model, and a drawing.

General findings

Students' different constellations for collaboration are displayed in Figure 4. To not overly extend the figure on the vertical axis constellations where students worked in groups of four, five or six (whole group) have been put in the same group. Indeed, all these constellations could in some sense be seen as whole group like constellation. Furthermore, it should be noted that only students' activities performed in the main group room could be coded due to the fixed mounting of cameras. For example, during episodes 5 – 59 Sven and Anders mainly worked at another place and the same was valid for Sine and Heidi during episodes 48 – 59. Although Heidi wore a GoPro camera it was mounted on her chest and thus it was not possible to discern her gaze and with certainty discern her interactions with other persons. Therefore, we have not yet fully analysed the recordings made by the GoPro.

Roughly speaking the work in the project meeting can be divided five phases. In the first phase from the start of the day until when Sven left at 0:44 (all timings in hour minutes from the start of recordings) and Anders shortly thereafter the students worked as a whole group. They ate breakfast together at the main group table. As they also informed each other of the present status of the work they had done hitherto and discussed the planning of the day we have seen episodes 1 – 4 as an on-task activity, although it also had an important social aspect.

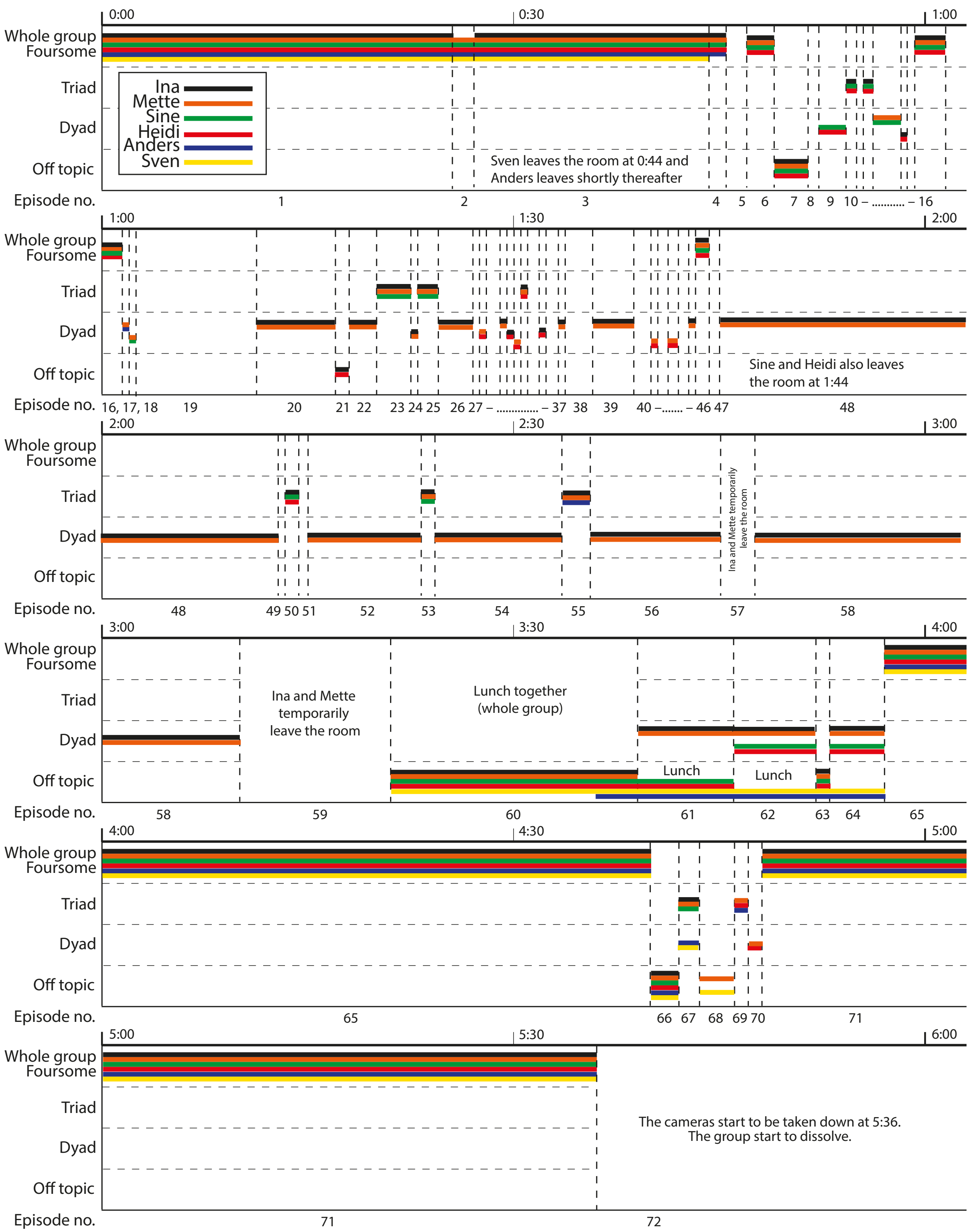

Figure 4. Timeline for students' collaboration in the project meeting displaying their different forms of collaborations during the meeting as seen in the main group room. Each student is colour coded making their participation in different constellations visible. The scale on the time axis is hour and minutes.

From 0:45 to 1:44 (episodes 5 – 47) we have a second phase there the male students Anders and Sven have left, and the female students Ina, Mette, Sine, and Heidi remains in the main room. To a considerable extent they work individually but this phase is interspersed with several longer and shorter collaborations in dyads and triads in shifting constellations as can be seen in Figure 4. Some "whole group" discussions in this group of four can also be seen. In turn 25 in transcript 2 it was noted that it was a 10.6 s pause between the dyad in episode 22 and the triad in episode 23. In a similar vein we usually observed pauses of 5 – 10 seconds in the interactions when students shifted from participating in one constellation to another as for example in episodes 30 – 33. In these short pauses the students would typically have a quick look in their computer, on a note, or to a drawing. To not clutter Figure 4 to much we have not represented these, very short, pauses in the figure. Nevertheless, we think that these pauses are important in the interactions and for the collaborative work.

A third phase is from 1:44 to approximately 3:10. In this phase it looks like the students work together in three different dyads (Ina + Mette, Sine + Heidi, and Sven + Anders). Through the fixed cameras we only have access to work by Ina and Mette. It could, however, be noted that the dyadic work in this phase is not static and we have "guest visits" for co-ordination purposes by Sine in episode 53 and Anders in episode 55. Moreover, in episode 50 Ina walks away for a guest visit to Sine and Heidi and in episode 57 both Ina and Mette walk away for a visit. Recordings by the GoPro-camera also might be interpreted as that Sine, Heidi, Sven, and Anders have worked together as a group of four during this phase.

The fourth phase can be seen as starting at 3:10 when Ina and Mette leaves to buy lunch. At almost the same time ten minutes later the whole group congregates at the main table to have lunch together (Anders, however, leave almost immediately to return 15 minutes later). At 3.39 Ina and Mette start to work together in a dyad and at 3:46 Sine and Heidi also start to work together in a second dyad. Anders is eating lunch for some more time and Sven is doing off topic tasks.

In the fifth and final phase starting at 3:57 the students' work as a collaborative group until the end of recordings at 5:36 (with a short break at 4:40). They present their solutions to different design issues to each other and receive feedback. But they also, as can be seen in Figure 3. and in transcript 3, receive creative suggestions from other group members which illustrates the strength of collaborative work. Furthermore, their work is coordinated, and plans are made for the presentation at the upcoming review seminar.

It could be noted from the compilation presented in Figure 4 that beside the common lunch there were very little "off-topic" activities observed. Indeed, in this group students' telephone conversations and messaging seem to be confined to the lunch break and the break at 4:40. Furthermore, it can also be noted that besides episodes 62, 64, and 67 no subgroups (i.e., dyads and triads) worked simultaneously in parallel in the main group room. The students split up and moved to different locations when they started to work in dyads for a longer time.

CONCLUSION AND DISCUSSION

This study set out to answer the research question *how could the dynamics of individual and collaborative work in students' group practices in a design project be described and visualised?*

In this study we have hitherto only have had time to do an in-depth study of the group practices in one collaborative design group. This somewhat limits the conclusion that can be drawn. Nevertheless, we argue that anyway several conclusions can be drawn from our findings. In the literature (e.g. Borgford-Parnell et al., 2013; Menekse et al., 2017) intra group practices in static groups are reported. On the contrary we found, by analysing video-recordings, that the fine-grained patterns of students' social interaction within the observed collaborative design group to be complex and dynamic and it display fluidity as well as structure (cf. Sørensen, 2022) as the students during the day worked in many different constellations. It was observed that students often changed constellations and break into subgroups of one, two or three students to do some work and to congregate later as a whole group. Thus, we found that the patterns of collaboration in groups practical day-to-day work were not static but displayed a myriad of different patterns. To our knowledge, this study is one of the first studies to report this fluidity of constellations and to report complex collaborative patterns in students collaborative group work.

Furthermore, in line with the observation by Ryberg et al. (2018, p. 240), we also noted that the distinction between cooperative and collaborative work seem to blur when we studied students' interactions in detail as they, in their activities, alternated dynamically between individual, cooperative, and collaborative patterns of work. Thus, our results challenge a naïve individual-collaborative-binary and a naïve cooperative-collaborative distinction.

For engineering education researchers to be able to make more realistic and sound pedagogical recommendations, and for engineering educators to make sound decisions, they need to have a good understanding of how students' design processes play out in reality (i.e., to have what is sometimes called "ecological validity"). As already mentioned, a limitation of this study is that we hitherto only have had time to study the group practices in one collaborative design group and it limits the pedagogical recommendations we can make based on our empirical material. Still, one conclusion is that localities where collaborative work is taking place need to be designed, or adapted, for flexible group work and another tentative conclusion might be that instructors should encourage fluid collaboration patterns in students' collaborative work.

Thus, our results points to the need to investigate group practices and individual and collaborative learning in design project groups and other collaborative learning environments in more detail. It would be important to better understand which features (e.g., collaborative patterns, skills needed by students, etc.) are important for successful learning and good collaborative work in students' collaborative design projects and how these can be fostered and developed in engineering education. We have collected a large corpus of video data from A&D-students at Aalborg University in their first, fourth and fifth semesters. For example, we have video recordings from four more groups of fifth semester A&D students. Thus, we have an excellent empirical material to continue study the questions raised by this study. For example, it would be interesting to compare the collaborative patterns of groups. Moreover, we have not in this stage of our analysis related the collaborative moves to the fine-grained content of interactions.

Finally, this study shows that the features of "Big Video" technologies and interaction analysis make them ideal for, in an unobtrusive way, study students' "messy", collaborative design processes in real educational settings.

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THE GREEN ENERGY TRANSITION - A CASE FOR LIFELONG LEARNING

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ABSTRACT

The EU has launched a series of ambitious plans to accelerate the energy transition, notable the 'Fit for 55' package that was presented by the Commission in July 2021. The target of the package is to reduce greenhouse gas emissions by 55% by the year 2030. Climate change mitigation through phasing out fossil fuels and becoming energy independent are central targets for the EU. The universities are supposed to be forerunners when it comes to research and education for providing the skills and competencies for enabling environmentally and economically sustainable development of society. However, when it comes to the energy transition, is the technology driven by the companies, with the universities just trying to keep up with the technical development? Are the skills acquired from traditional engineering education enough to support the green transition? In this paper, a qualitative study on how the current curricula support the green transition from the viewpoint of university-level engineering schools in Finland is presented. Based on this study, an analysis on potential changes beneficial for empowering the students to be able to rapidly contribute to the energy transition is performed. In addition, it is discussed how the current offerings could be used for lifelong learning to contribute to the green transition.

KEYWORDS

Green transition, Energy technology, Sustainability, Continuous education, Lifelong learning
CDIO Standards: 2, 3, 4, 5, 12

INTRODUCTION

Over the past few years, we have seen a series of initiatives by the EU to accelerate the energy transition, for example, the Battery directive(European Commission, 2020a) and the EU strategy on offshore renewable energy (European Commission, 2020b). To further accelerate the transition, the EU Commission presented its 'Fit for 55' package in July 2021 (European Council, 2021). The proposals included in the package aimed at providing a coherent and balanced framework for reaching the EU's climate objectives. The goal is to reduce greenhouse gas emissions by 55% by the year 2030 and to make the EU climate neutral by 2050. The Russia-Ukraina conflict starting in 2022 made all of Europe aware of our dependency on fossil fuels.

The need for a rapid transition to sustainable and fossil-free energy systems was suddenly not only policy-driven but driven by a pan-European energy crisis. This gave rise to the RePower EU plan (European Commission, 2022), which aims to make Europe independent from Russian fossil fuels well before 2030.

The universities are supposed to be forerunners when it comes to research and education for providing the skills and competencies for enabling environmentally and economically sustainable development of society (United Nations, 2015; UNESCO, 2021). Also, the CDIO Standards have been updated to include these themes (Malmqvist et al., 2020). Sustainability was one of the development targets already in the previous major revision of the CDIO Syllabus (Crawley et al., 2011). Furthermore, the crucial role of engineers in sustainable development was taken as one of the main motivations also for the recent update of the syllabus (Malmqvist et al., 2022).

However, when it comes to the energy transition, is the technology yet driven by the companies, with the universities just trying to keep up with the technical development? Are the skills acquired during university studies enough to support the green transition that is needed in the energy sector, the industry and society in general? In this paper, we present a qualitative study from the viewpoint of the universities in Finland on how the current engineering curricula support the green transition. Based on this study, we perform an analysis of which changes would be beneficial for empowering the students to be able to rapidly contribute to the energy transition. In addition, we analyse how the current offerings could be used for lifelong learning, providing knowledge and thinking models for professionals in the industry, to contribute to the transition and the conclusions of what actions the universities should take.

The research questions that were addressed in this work are the following:

1. How well does the current curriculum support the energy transition?
2. What action (curriculum changes) should be taken to better support the energy transition?
3. What is the role of lifelong learning for the energy transition?

The research questions are addressed by a literature review, interviews of representatives of the seven universities offering engineering education in Finland, and by an analysis of the results achieved.

ROLE OF HIGHER EDUCATION IN THE ENERGY TRANSITION

On June 16, 2022, the European Council adopted a recommendation (European Council, 2022) for member states to support policies and programmes about learning for the green transition and sustainable development. Members states are recommended to step up efforts to support education and training for green transition for learners of all ages. University engineering education has a special role, as technology for green transition needs to be available to enable this transition.

In a study by Biancardi et al., 2023, the authors have conducted a study on student perception of sustainability and energy issues. Earlier studies on how students and professionals can be prepared for the energy transition emphasize the integration between different disciplines (Huijben et al., 2022) and the importance of bringing students closer to real contexts (Colmenares-Quintero et al., 2023). Others bring up potential pitfalls with focusing on the topic too narrowly as there are discrepancies between what is technically feasible and socially desirable (Sakellariou and Mulvaney, 2013). Indeed, the energy transition ought to be addressed from a broader sustainability transition perspective, for example, in the context of the UN's Sustainable Development Goals (Dziubaniuk et al., 2022).

Many previous authors have addressed the need for a change in curriculum for supporting sustainability goals. It is often mentioned that education needs to be multidisciplinary, including both technical and social aspects of sustainability in education (Krupnik et al., 2022). Lozano et al., 2022 mention the role of a holistic approach to teaching for sustainability. There are however not many research papers that directly address the analysis of the technical content of education required for green transition and sustainability.

A recent Finnish report has analysed the effects of the green transition on educational requirements in engineering. The report looks at the skills needed in three related sectors: the process industry (a big off-taker for green energy), the energy industry (production) itself, and the construction industry (building and installing the new energy system) (Wikman et al., 2022). The report furthermore distinguishes between three types of skills needed for the transition in these sectors: core technical, system-level, and complementary skills (Wikman et al., 2022). With complementary skills, the authors refer to safety, digital solutions and modelling, but also more recent knowledge such as circular economy and environmental impact assessment.

Another analysis report published by the Association of Nordic Engineers (DAMVAD Analytics, 2022) provides a more detailed list of competencies needed for a sustainable future. The main areas of technologies are listed as Power-to-X, wind power, battery, hydrogen, biomass, geothermal and carbon capture technology. It is mentioned that engineers are indispensable for reaching Nordic net-zero emission targets. Overall themes that need to be addressed are the electrification of society, systems thinking, knowledge sharing and big picture thinking, the increasing role of data and digitalisation, and the demand for engineers with soft skills. The report also mentioned the need for collaboration between universities, and also between countries, to ensure that knowledge from one country can be reused in another. One such example of collaboration is the BotH2nia hydrogen cluster (both2nia.com), where the partners have a common set of events and education on wind power and the hydrogen economy.

Lifelong learning and green transition

Different opportunities for continuous and lifelong learning have been discussed widely in different arenas. The ageing population in several countries, including Finland, together with rapid technological development has raised concerns about the universities' ability to contribute to the needs of future society. Sustainability and energy transition are typical examples of topics that require multidisciplinary competence development of professionals working in the field. Learners of all ages and backgrounds should be able to access high-quality, equitable and inclusive education and training on sustainability, climate change, environmental protection and biodiversity (European Council, 2022).

The Government of Finland published a new National Higher Education Strategy for Lifelong Learning recently (Ministry of Education and Culture Finland, 2022). One of the goals of the strategy is to strengthen and clarify the role of higher education institutions as providers of different types of courses and other research-based activities contributing to the lifelong learning of individuals as well as the development of organizations. These learning opportunities should be easily accessible and available. For example, different open education solutions (e.g. MOOCs), and course designs based on called micro-credentials (European University Association, 2020) are expected to facilitate learning. Furthermore, closer connections between lifelong learning and RDI activities are expected to increase the societal impact of the universities.

What does the landscape look like in practice at the moment? The challenge to create such high-quality educational offerings that are able to meet individual, industrial and societal expectations is not trivial. Creating timely, learner-centred and economically efficient learning solutions that are easily available on digital platforms is not enough. Also, both individuals and organizations shall actively and continuously seek new knowledge and utilize these opportunities for growth. According to Eurostat (2022), adults in the Nordic countries participate in different education and training very actively compared to the EU average. However, participation in open university courses is strongly field-connected. For example, professionals in the field of Education and Humanities participate actively in these courses whereas Engineering and Science professionals are clearly underrepresented. That is, there should be room for the development and co-creation of new learning innovations.

METHODOLOGY: INTERVIEW OF FINNISH ENGINEERING UNIVERSITIES

Research approach

We established a qualitative research design covering all universities offering engineering education in Finland. A qualitative approach was chosen as the topic is new and we wanted to form a deeper understanding of all the nuances of how engineering schools are addressing the energy transition or of the underlying motives and personal reflections of faculty at these schools. The national focus is justified by the wish to account and control for various differences in national educational systems and the debate around that.

Selection of interviewees

Following our qualitative approach, we looked for professors and lecturers in the field of energy engineering (or closely related to it) at seven universities offering engineering education in Finland, that is: Aalto University (Aalto), Lappeenranta-Lahti University of Technology (LUT), Tampere University (TUNI), University of Oulu (OY), University of Turku (UTU), University of Vaasa (UWA), and Åbo Akademi University (ÅAU). We managed to cover at least one interviewee from each university. While it is impossible for one person to oversee all courses and degree programs in their institute, these contacted interviewees were very helpful to explore and set a research agenda. In total, we made ten interviews (meaning we interviewed two persons at three universities and one representative from the rest).

Data collection and analysis

For the interviews, we developed an interview protocol (see Appendix 1), which was derived from our perception of important topics underlying the overall research question. The interviews were semi-structured following the interview protocol in an open-ended way, meaning that the interviewees were free to elaborate on the topics beyond the immediate answer itself. The interviews lasted 30-60 minutes and were performed in December 2022 by one of the authors of this article. Structured notes were taken during the interviews. We used thematic content analysis to extract findings of interest for our study. This essentially meant that we organized the results in groups following the structure of the interview protocol (see the results section).

RESULTS

Interview results were arranged based on the questions and conversations during the discussions. The responses from different teachers belonging to the same university were counted to create transparency. The case concerns different experiences and practices associated with belonging to a geographical area and department. Our aim is to provide a guideline for a green energy transition in the context of lifelong learning for engineering universities in Finland. This would increase knowledge-base in general and enhance the curricula in accordance with the needs of society.

Courses supporting the new energy technology

The interview starts with a general question to the interviewee meant to analyse at a larger level whether there are courses on specific domains that were communicated with the interview question. This topic brought up a discussion on what it truly means *"New"*. The reality is that sometimes "new" simply means improvements to the present technologies. Many of the interviewees responded that the universities where they work are moving towards renewable energy teaching and all courses are oriented towards this.

Figure 1 unveils that hydrogen, photo-voltaic, bio-fuels, heat recovery and energy storage, are the most mentioned topics, part of the energy transition covered within the universities curriculum. Other technologies like wind and battery had a lower response rate pointing towards being moderately thought to students. Fuel cells and new fuels are novel research topics on energy transition at the beginning of the research, and therefore not many technical universities are putting effort into this. One respondent noted that mechanical parts are a great addition that could better support the knowledge given to students. Other respondents remarked that environmental engineering is a unique subject studied within the university.

Figure 2 emphasises energy transition as the highest encounter within the course examples given by the interviewees. Some mentioned that energy transition is only a chapter or part of the course curriculum. Others mentioned having specially employed professors on energy

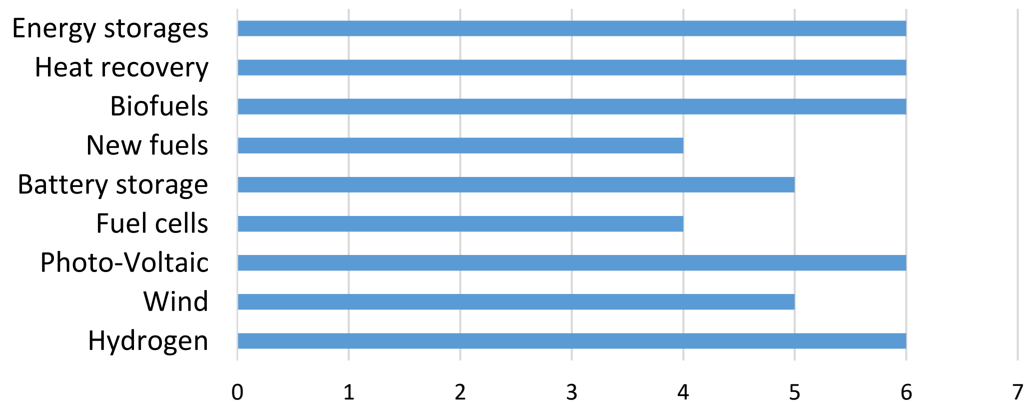

Figure 1. Number of universities adopting topics in new energy technologies courses in their curriculum

transition that could cover both technical and socio-economical aspects.

Changes compared to five years ago into energy transition

There seem to be clear differences in the educational strategies of the different universities. Some choose to have stable five-year curricula while others change their plans annually or bi-annually. Yet, many interviewees stated that their curriculum is updated continuously according to the industries' needs and the advancements in technology and society. An interviewee noted that the university's strategy has been changed towards topics in energy and carbon-neutral technologies.

Students seem to have more trust in the universities' curricula after topics in statistics and process engineering have been incorporated into courses. It is justified by the numerical values incorporated within courses that give more value to the students. Moreover, applications and practical examples (or hands-on experiences) are considered very crucial for students to understand the motivation behind each course. The hybridization and electrification of the power trains are as well novel addition. A minor in sustainability and a master's programme in environmental engineering are very close subjects to the energy transition. Energy scenarios and power to Ex (energy) technology-connected courses were mentioned, too. On the other hand, one respondent noted that there have been no drastic changes made in the curriculum compared to five years ago.

Improvements in supporting the new energy technology

The most common answer to this question was the lack of highly-skilled personnel trained for teaching courses connected to the energy transition. However, international cooperation and resources are bringing new opportunities and improving the ways of teaching at Finnish universities and, therefore, help keep the country stay at the same technological level as others.

Interviewees noted the need for intensified research on heat systems, energy storage, bio-gas

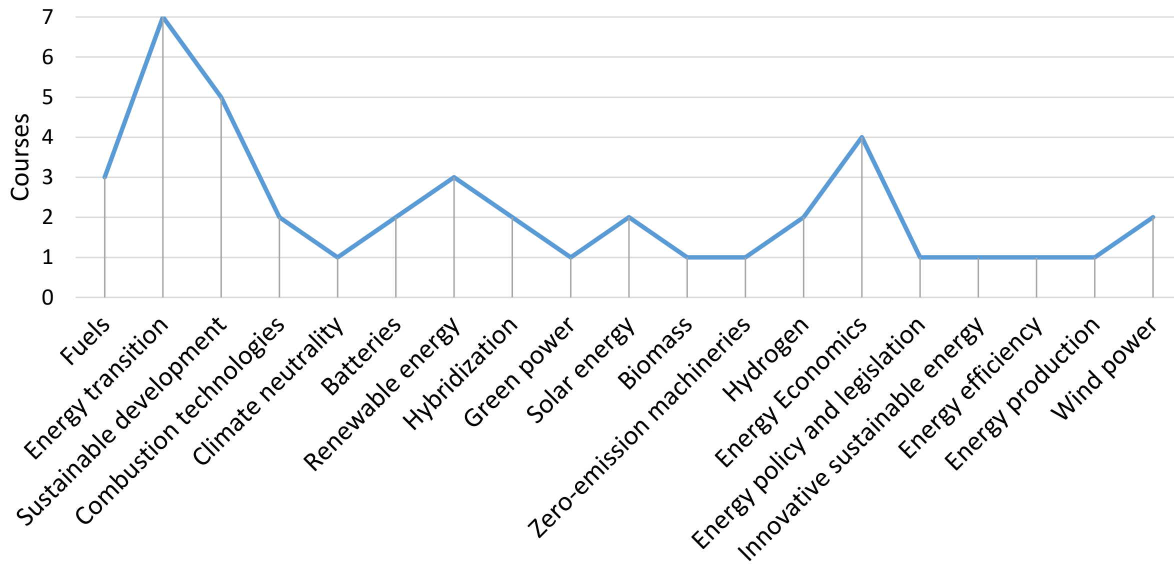

Figure 2. Courses that support the new energy technology

cleaning techniques, system flow detection, and small modular reactors. Studies on how technical and financial energy transition fits into the social sector's needs to proceed simultaneously. Also, new initiatives to reduce the cost of new technologies (e.g., hydrogen production) are needed. Energy systems designed to produce biomass are an addition that would facilitate the existing processes because the current price for biomass fuel is many times higher than that of fossil fuels. One interviewee raised that, at a university, one needs to have the ability to be self-sufficient. Given this, the values of the university connected to energy transition are sufficient motivators to continue the activity within the unit.

Cross-disciplinary courses or learning experiences

The previous topic raised responses where some noted that their departments don't currently have cross-disciplinary courses or external cooperation. Yet, some units are utilizing courses on different topics such as strategy and vision making, governance, policies and laws on energy transition given by other universities. Others have policies and legislation deeply incorporated into their own curriculum. Other examples of cross-disciplinary courses include topics in hydrogen, electrical energy storage systems, materials sustainability, energy policies, fuels, power plants, and life-cycle analysis.

The sustainable urban energy course is an example where students incorporate sustainable development and model energy at a city level. The *climATE* programme of Aalto University is a research and art exhibition on climate change and food systems (Aalto University, 2019). One interviewee noted that sustainable values transmit to people through their habits. Therefore, there is a lack of social science to be added to curricula. The mentioned topics and courses are listed within the educational program of the interviewed universities.

Courses that support the business modelling of the new energy markets

Several interviewees mentioned there is neither space in the curriculum education nor availability of courses in business modelling of the new energy markets. Yet, a major challenge when modelling the new energy systems is whether they are economically competitive or not.

This topic is present in the following courses that are part of the interviewed universities' curricula: Sustainable energy, Feasibility, Electrical energy storage systems, Fuel and Off-grid value chains, Business models and Entrepreneurial journey, Energy market systems, Turning circular economy technologies into business - commercialization and business model development.

An example is a course called *Sustainable Energy Project*, where students need to analyze the feasibility of an energy production and management design assignment. Another interesting course is called *Power Exchange Game for Electricity Markets*, where students trade electricity using actual data and see how their decisions result in profit or loss.

Lifelong learning

Few interviewees mentioned that their universities do not currently target lifelong learning students due to a lack of motivation, time or other projects. Occasionally, companies want to improve the employers' competencies and send their employees to attend university courses. Some courses are good bridges between universities and companies. An example is the *FiTech* (Vasankari et al., 2021) platform where many of the universities are sharing their courses. In addition, some universities provide special courses designed for lifelong learners.

Lifelong learners are both a challenge and an opportunity for universities. Opportunity comes from the valuable feedback that specialists with substantial years of field experience could be able to provide. One of the practical challenges of lifelong-learning-oriented courses is that students are often losing their interest during the course (or feel the time pressure from their ordinary work making the unable to commit to typical university courses) and, consequently, the courses need to be split into micro-credit modules. Business thematic courses have previously solved the need for lifelong learning. Furthermore, there are Massive Open Online Courses (MOOCs) designed, for example, for climate actions in the transport sector and achieving climate neutrality. Such an example is the *UNITE* (Hetemäki et al., 2022) project that is responsible for developing new solutions for meaningful and sustainable interaction between people, forests and technology.

Statistics related to energy-related students/year, courses and teachers

Statistics related to energy students, courses and teachers from these seven Finnish universities were collected. The question aimed to provide an understanding of a numerical approximation based on the interviews compared to the data available in the national educational statistics database *Vipunen* (Table 1). In this graph, we see that the interview results give a much larger estimate of students in the area compared to the numbers in the *Vipunen* database for LUT. This also reflects the overall feeling of the culture of future energy relevance for the university that was perceived in the interview.

LUT has the highest number of energy-related courses; approximately 250 courses in total. Next are Aalto and TUNI with 100 and 70 energy-related courses respectively. The other respondent universities have between 2 to 20 courses in this category. In addition, the number of teachers related to energy was discussed, too. The findings were similar to the question concerning the number of courses. LUT has approximately 200 teachers in energy Aalto and TUNI have

Table 1. Number of students studying energy-related topics annually - interview results compared to statistics in the Vipunen database

University	Total Vipunen	Total interview
University of Vaasa	453	10
University of Turku	192	26
University of Tampere	1506	700
University of Oulu	1098	50
Lapeenranta-Lahti University	2142	4000
Åbo Akademi University	176	35
Aalto University	3880	150

roughly 70 teachers each, and the rest less than 15.

Energy saving actions of the university

We also wanted to understand to what extent universities live as they teach, that is, how well the energy transition is integrated into the universities' operational activities. The energy crisis has brought new guidelines and rules for different organizations, including universities and student dormitories. The University of Turku made a strategic objective and commitment to being carbon neutral by the end of 2025 (Kola, 2020). As a general rule, the overall indoor temperature at the universities has been lowered, and many have reduced their real estate area moving different departments in the same building, or into a new structural and energy-efficient facility. The changes include replacing laboratory equipment with less carbon-intensive, adjusting the duration of fume cupboards, and optimising the period and power of air conditioning. Other suggestions for energy reduction are ride-sharing, commuting using bikes, and ongoing recommendations related to the working practices of personnel (the footprint of own daily work). Some energy-saving actions (e.g., temperature droppings) brought negative feedback due to the uncomfortable environment for developing the activity within office areas.

DISCUSSION AND CONCLUSIONS

The aim of this paper was to analyse how well the curriculum of engineering education universities in Finland supports the rapid need for an energy transition that we have globally, in Europe, and locally in Finland. We also analysed how the curriculum is changing and the role of lifelong learning in the transformation. In order to achieve the results, an interview-based qualitative study was performed with representatives from all seven universities providing engineering education in Finland. Previous research did not give much information on the actual implementation of green energy transformation curriculum changes. Several research articles stressed the need for such modifications, especially the need for a multidisciplinary curriculum, especially including social sciences and technology. However, very few actual examples of how that should be done were mentioned. That does not imply that such activities have been implemented, only that there is very little research on the volume and effect of such implementations. The best source of information on practical curriculum changes needed was actually provided by engineering association publications, and not by academia.

The interviews performed in this research however gave substantial insight into the activities in Finland. The seven universities providing engineering education have all taken considerable steps to change the curriculum to support energy transformation. All universities have introduced courses on new energy, and many existing courses have been adopted to support the new energy. However, strong multidisciplinary efforts are not yet visible, supporting the society-wide aspects of the energy transformation. Many of the changes are also more incremental than radical changes in the way education is performed and built up.

There is clearly a need for nationwide collaboration when it comes to lifelong learning. Emerging energy technology does not yet have a standardized learning material, generated teaching material should be reused between sites and made available for persons already in the working life. This way of working is not well established and needs a cultural change in the organization. Digitalization of educational resources gives a good platform for future collaboration.

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APPENDIX

Questions used for the interviews are the following:

1. How well do you think your curriculum supports the new energy technology? e.g., hydrogen, wind, photo-voltaic, fuel cells, battery storage, new fuels (hydrogen, ammonia, methanol), biofuels, new forms of waste heat recovery (data centres, marine systems, wastewater), energy storage systems
2. Examples of courses that support the energy transition?
3. What has changed in your curriculum during the last 5 years supporting energy transition?
4. What do you think your university should do to better support the new energy technology?
5. Do you have cross-disciplinary courses/learning experiences? (e.g., psychology, social policy-making, legislation)
6. What courses support business modelling of the new energy market?
7. Lifelong learning: Do you target lifan elong learning students (professionals out there) –> what kind of offerings (MOOC, on-site intensive courses, micro-credentials)
8. Number of energy-related students (total/annual)
9. Number of energy-related courses em Number of teachers related to energy technology
10. Did your university implement any energy-saving actions?

STUDENT REFLECTIVE PRACTICE AS PART OF ENGINEERING PROGRAMMES

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ABSTRACT

Reflective learning can be defined as "*practice which involves the development of learning and understanding through self-review to help determine progress against goals and future learning needs*". In a CDIO context, the use of reflective learning has found its way into the most recent iteration of the syllabus while it can also be argued that self-review is, in particular, a part of Standard 8 - Active Learning. This work looks at a survey (n=38) carried out among academic staff involved in CDIO and in the wider engineering education community to establish the extent to which reflective learning is embedded in engineering degrees and how, at the highest level it is taught, implemented and assessed. The survey also looks at motivations, barriers and best practice in the field. Among the findings, respondents to the survey were enthusiastic about the topic as might be expected in a voluntary survey, however there was more skepticism as to whether students would see the value of the approach and so may not engage. Reflective journals and/or end of module reports and reviews were common tools used to embody reflective practice into activity, though these might be part of a more general activity or assessment and not be entirely focused around reflective practice. Key barriers to adoption of reflective practice included the pressure on an already overcrowded syllabus and students struggling to engage in the process, staff reporting that structure and frameworks need to be used to develop true reflections as opposed to simple records of events. The work concludes by highlighting some routes forward for the approach both in terms of implementation and possible development of the methodology.

KEYWORDS

Reflective Learning, Learning Approaches, Survey, Standards: 3, 7, 8, 11

INTRODUCTION

CDIO emphasises an active and engaged approach to engineering education with students being fully participating partners in their own educational and personal development, not simply acting as consumers of, or depositaries for, didactically delivered knowledge. The learning within CDIO programmes is often experiential, often integrating between disciplines. This is exemplified in a number of standards, including standard 5 : Design – Implement Experiences and standard 8 : Active Learning. The learning experiences associated with these approaches may be authentic but may not always be as explicitly expressed as in more conventional methods. Further the breadth of integrated content may also expose students to their weaker and stronger areas in a more subtle way than traditional programmes with very discrete and often unlinked subject areas.

To fully realise the opportunities afforded by the authentic and integrated approach of CDIO, greater ownership of the learning process needs to reside with students and as such, skills in critical self-reflection to guide the learning needs and growth of each student, it can be argued, are an important – if not essential - part of the CDIO experience. Indeed, there is reference to student reflective practice in the rationale for Standard 8 ("*….they recognize for themselves what and how they learn"*) and as an assessment method (*Standard 11*). Meanwhile the most recent version 3.0 of the syllabus has seen this competence recognised with formal inclusion of reflective practice (*2.4.2 : Self-awareness, self-reflection, metacognition and knowledge integration* & *3.2.3 : Written communication > Reflective writing (write to learn)*) (CDIO (2022)). Further, the ability for students to self-reflect on competence levels and learning needs is an important skill required in the support of lifelong learning, as graduates move beyond the externally mapped learning associated with school, college and much of university education to a more self-prescribed pathway following graduation (Bergland (2018)).

This paper asks the degree to which reflective learning practises within the general engineering education community including but not exclusive to those utilising CDIO, examining motivations, methods and outcomes. This is then coupled to a survey of CDIO practitioners to understand the extent to which reflective learning appears within the curriculum, the value placed on this by students and staff, the impact of this approach and barriers to implementation. This highlights opportunities offered by this approach but also some of the cultural and practical challenges associated with brining in reflective practice.

LITERATURE REVIEW

Despite the overall recognition of the importance of reflective learning practices in professional education, there is no consensus on the definition and we can find various approach to describe this concept (Mann et al., 2009). According to Dewey's (1933:9) frequently cited seminal work, reflection is an "active, persistent and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends". From this perspective, reflection is a continuous process happening in community as a "meaning-making process" based on learners' experiences and ensuring a deeper understanding of these experiences at a different level (Rodgers, 2002). For Shön (1985), reflection is considered as an iterative process in which reflection of an experience produce a new understanding that will change the learners' reaction to the future experiences. This iterative reflection is often integrated in the various theoretical models of reflection (Mann et al., 2009). Regardless of multiple approaches and interpretation of reflective practice even inside of the same discipline, we consider it as a part of the process of lifelong learning allowing to individual learner being self-aware and critically evaluating own actions to develop their understanding. Consequently, self-awareness and critical thinking are regarded overlapping reflexivity in the reflective practice (Finaly, 2008).

Reflective practice is making an emerging contribution to Engineering Education (Sepp et al., 2015) to the professional development of engineering students' through numerous transversal or soft skills' development. In their four level conceptual model of reflective engineering, Klaassen et al. (2021) put emphasis on the development of these transversal skills, ideally in a challenge-based education environment, for well preparing graduate engineering students to became a ‘reflective engineer’ able to answer to their future professional challenges. In the same line, Berglund’s (2018) empirical study provided evidence of engineering students’ skills development in their (1) personal effectiveness (personal management), (2) social competence (teamwork and communication), and the engineering professional role (engineering roles) through reflective practices. His work highlighted the potential benefits of reflective practices on engineering students’ professional development allowing a better preparation for their future professional career. Also, the experience of student reflection is highlighted in a number of CDIO conference papers (e.g.: Junaid et al., (2018); Cheah et al., (2019), Seidel et al., (2011); Wallin et al., (2016)). Typically, these involve the most frequent implementation of reflective practice as part of project or problem based learning environment with tools such as diaries or journals used to help students draw out the learning from project experiences.

As Eshuis et al. (2022) pointed out in their recent study, students have a strong recognition of the importance of reflective practice for becoming a professional engineer but seem not satisfied with the current implementation of reflective practice in their curriculum. Surprisingly, reflection reports were the most frequently applied method in their study programs that was perceived by students as the least meaningful and they would prefer reflective conversations with study coaches indicating the important role of teachers in reflective learning. Similarly, several authors (Morgan et al. (2021:13) observed, despite the perceived value of reflective practice, engineering students’ showed reluctance and a generally low level of reflection (only some students provided a meaningful reflection). As reflective practice is very different from the traditional teaching and learning practices, “instructors should provide this emphasis in the assignment instructions, alongside the reflective prompts”. Therefore, teachers play an important role for giving clear assignment and guidance by supporting students’ all along of their reflective practice in a persistent way (Cosgrove et al., 2014) over a longer period to a better benefit (Wallin et al. 2016).

Regardless of the difficulties in the implementation and evaluation, the use of reflective practice have numerous potential benefit for engineering students. One of the most important is the improvement of the academic performance and social engagement in their studies (Menekse et al., 2022). For George (2001), who reported also students’ reluctance for this non-conventional learning practice, there are multiple benefits for engineering students like the development of a wide range of transversal skills (communication, lifelong learning, self-awareness of learning strategies) and a better efficiency in the professional work. In his current study, Zarestky et al. (2021) provided evidences that the use of reflective practice was helpful in the development of engineering students’ metacognitive awareness, self-regulated learning behaviors, problem-solving, and critical thinking skills. As mentioned earlier, reflective practices happen in the interaction with others (Rodgers, 2002) therefore supporting students’ relational skill and attitudes (e.g.: open-mindedness).

METHOD

To investigate the use of reflective practice in engineering degrees an online survey was developed to which academics involved in CDIO and Engineering Education in general were invited.

Survey Design and Approval

The survey featured a blend of demographic data including participant's subject areas, work role and geographical region. Primary data was then gathered using multiple choice and Likert type questions to gather data on the extent of reflective practice, methods used and attitudes to this approach. A final question was added to allow participants to optionally share good practice in this area or report practices which may not have worked as well as hoped. The survey was anonymous to encourage open responses. The survey and general data gathering and use processes were approved via the ethics committee of the College of Engineering and Physical Sciences at Aston University (ref : #EPS21011).

Participants

Participants were invited from the list of "People at CDIO Member Schools" on the CDIO website database. Invites went out to academics from all regions however the nature of current CDIO demographics meant some regions received greater coverage than others. Some invites also went out directly to others from the wider UK & Ireland CDIO community and the wider engineering education sector. Around 40 responses (n=38) were received and feature in this study.

Limitations

As with any voluntary survey, participants will be more predisposed to take part in surveys in areas of personal interest and this will skew results against those which might be gathered by a more general population of academic participants. It was also the case that many of the larger CDIO institutions had several people invited to take part and so it may be some responses may be replicated among colleagues. While offering some insight into techniques used in reflective practice and opportunities and barriers associated with its adoption, detailed drawing out of the specifics of these matters were limited by the use of a survey as opposed to an interview.

RESULTS

Demographics

Figure 1 shows some of the participant demographic data gathered in the survey highlighting a strong mechanical and aerospace cohort with most being at lecturer level.

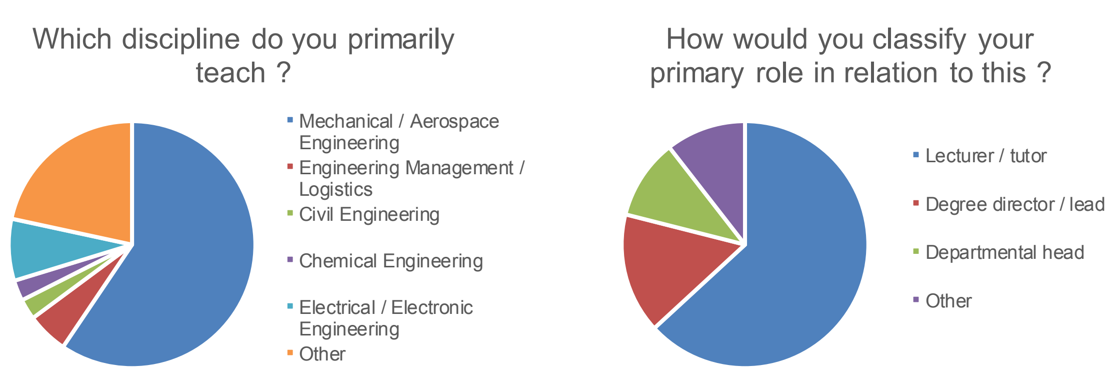

Figure 1. Partial demographic data of participants in survey

Implementation Approaches

Figure 2, shows some of the initial data gathered on how reflective practice is deployed. It is notable that reflective practice is embodied in range of activities, is indirectly assessed through these but it may often not be formally taught.

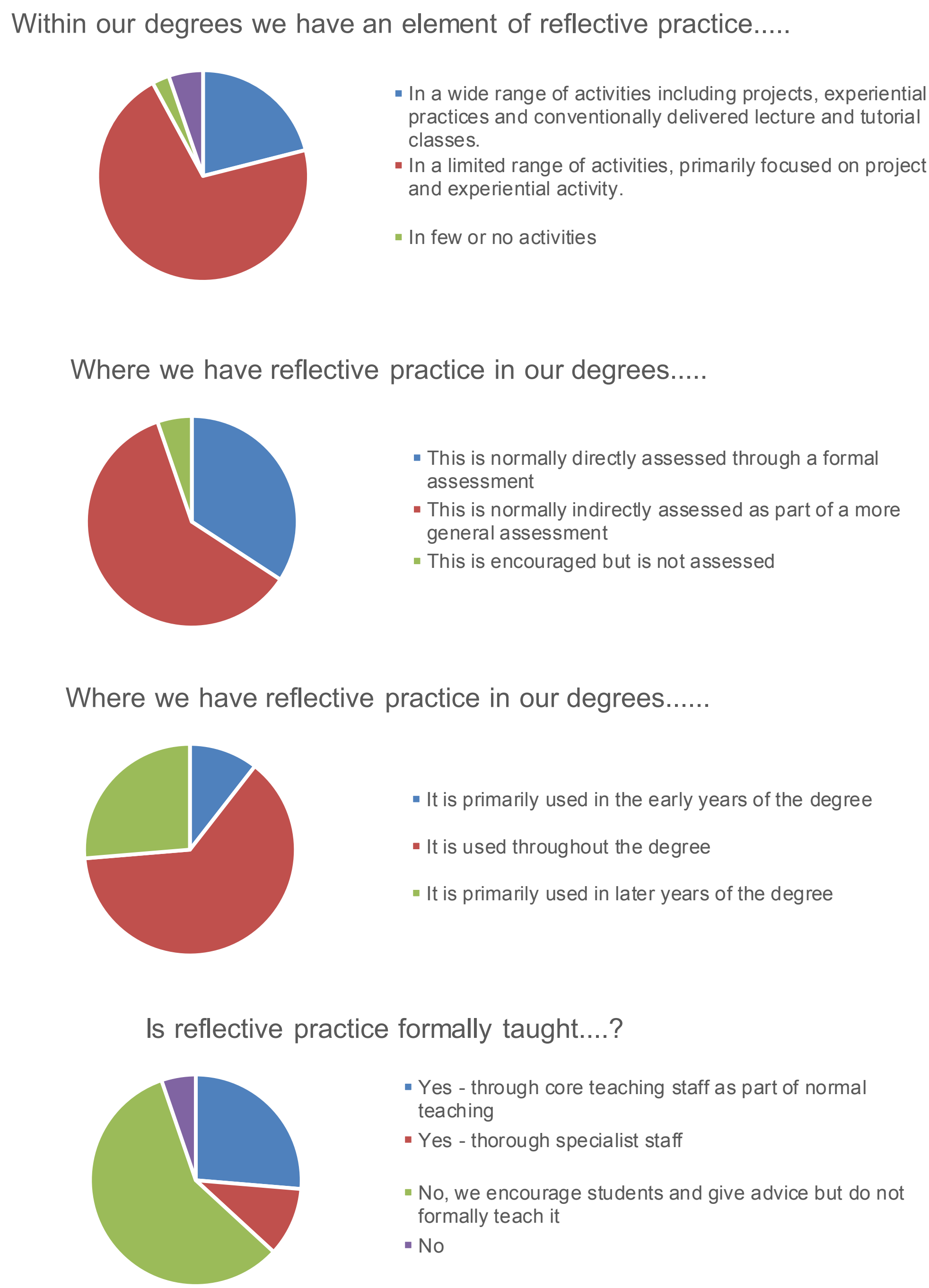

Figure 2 : Approaches to Implementation of Reflective Practice

Implementation Methods

Figure 3 highlights a range of different measures used by respondents to help embed reflective learning in degrees.

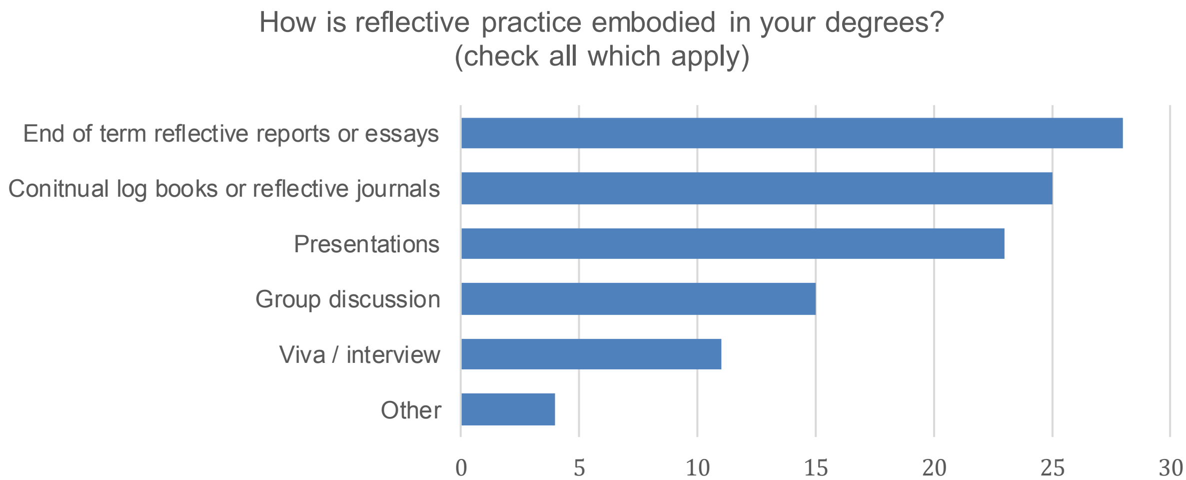

Figure 3. How reflective learning is embedded in degrees.

Perceived Importance

Figure 4 highlights different levels of perceived importance of reflective practice as recorded by the survey participants. As can be seen the survey participants were very enthusiastic about this theme but felt their colleagues may not be quite so positive and that there may be a further reticence or lack of awareness among students of the benefits of the approach.

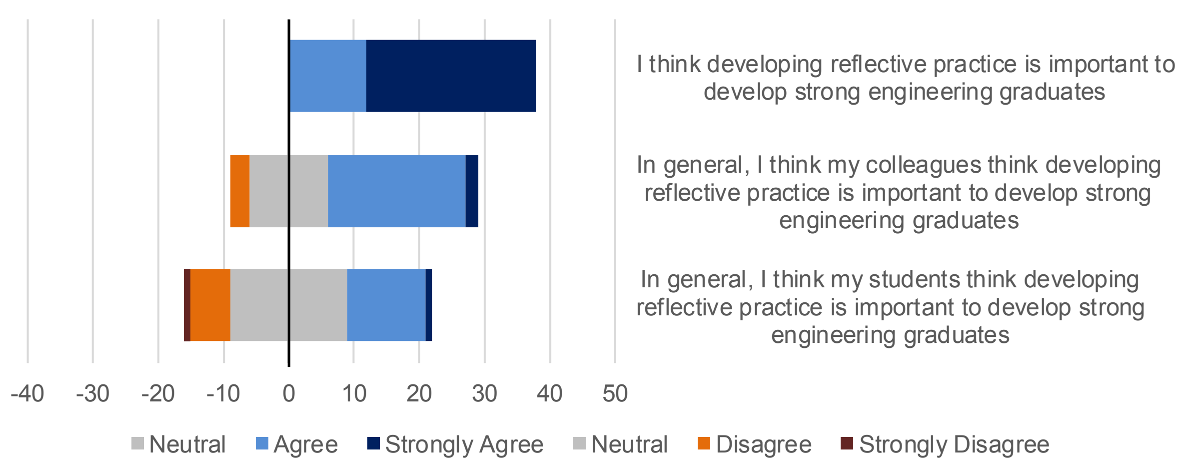

Figure 4 : Perceived importance of reflective practice

Barriers and hindrances

Figure 5 reports the degree to which participants felt certain factors act as barriers or disruptors which impact how reflective practice is deployed. Concerns regarding the ability to accommodate the approach in a typically busy engineering curriculum gave greatest concerns while hesitancy of both staff and students to embrace reflective practice in the curriculum were also prominent.

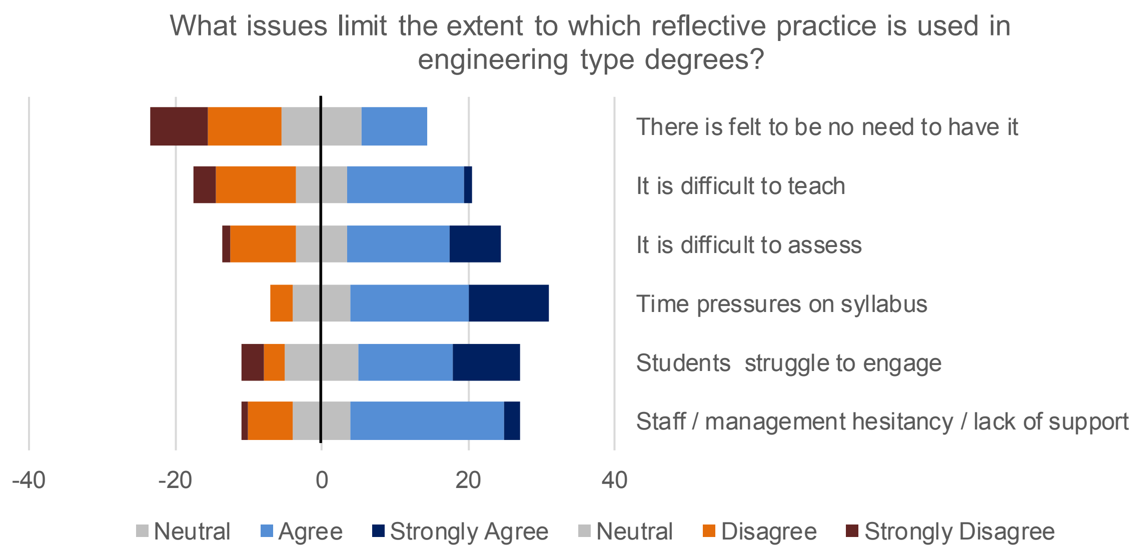

Figure 5. Factors hindering use of reflective practice

Benefits

Figure 6 illustrates a positive response to a range of potential benefits of reflective practice.

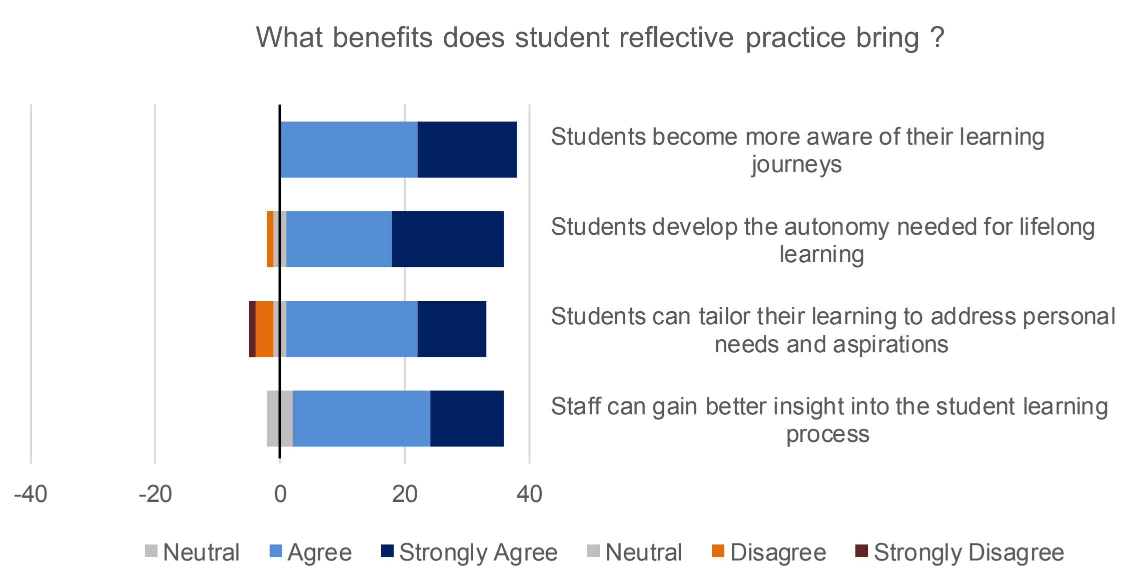

Figure 6 : Possible benefits of Reflective Practice

Learning from experience

In addition to the multiple choice and Likert scale questions, the survey also featured an opportunity for participants to share experiences of approaches to reflective practice with around 60% of them choosing to do so.

A range of activities were discussed by participants including project based activities with reflective activities including bi-weekly reports, end of module self-evaluations and peer and individual reflections. For example one respondent reported *"each student is required to perform a retrospective review of their own experience and how to enhance it in the next semester project in addition to a group evaluation of the work performed*".

Good practice was reported at different stages in the student learning journey. An introductory ice-breaking project, "Project Zero" was reported to lay foundations for reflective learning and *"create a positive attitude and experience for all the students as even those who perform poorly receive constructive feedback to help them with their first project*".

There were also mixed responses regarding what worked well with regard to how students felt about exposing their reflections to others with one participant reporting that *"I have tried this in various ways and have experienced a marked tendency towards non-participation in a public forum - it has to be very anonymous to work"* while whether the work was assessed or not could impact engagement *"Students are not willing to write or share reflections with personal tutors, perception is that it needs to be assessed to have value".*

Several reported that getting students to reflect effectively was sometimes difficult; *"very few actually reflected on their learning and the majority just reported what they did on the project"* with others reporting the need for significant support needed to go beyond simple reporting of experience and look forward; *"….needed guidance questions that point specifically to areas where we need students to reflect on, otherwise they tend to write narratives on what they had done"*. This however would not always deliver as hoped; *"We had rubrics to guide students but no explicit explanation are given. Students are expected to go thru' the rubric themselves, and as a result I don't think many did."*

While logbooks and reviews were quite common novel thinking included the use of role plays, *"where students are asked to reflect over the task and the development of the exercise, the group dynamic and their learning".*

DISCUSSION AND CONCLUSIONS

Reflective practice is widely considered by most CDIO practitioners as an important part of the skill set of both students and graduates but is not always recognized by students and can be difficult to implement into programmes through pressure on staff and curriculum time and hesitancy from colleagues and students to embrace the approach. It is a part of the CDIO methodology having found its way formally into the syllabus in the 2022 revision. It is also however a part of Standard 8 on active learning but may often get lost in interpretation with the focus of the standard on practical project type learning.

A wide range of different models and approaches are used to support reflective learning, though there appears to be no failsafe approach to implementation. While some methods work well for some students, for others, full engagement needs significant support and guidance.

The most popular approaches used to engage students in reflective learning were ongoing reflective journals or end of project reports with most of the academics participating in the survey using these approaches. These are pragmatically attractive in being fairly easy to administer and leaving a written record of reflection for assessment or review. Students often struggled with this approach however and could not provide meaningful personal reflection as opposed to simple recording of facts. This is likely to be a mix of factors with engineering students general writing abilities and an unfamiliarity with self, as opposed to tutor, review. Aspects relating to the personal nature of reflection have also been reported as an issue in other fields (Fernández-Peña, R et al (2016), Leering (2019) Thomson et. al. (2019)). Students can become reluctant or anxious to share weakness or vulnerabilities to tutors or can be concerned over privacy. It would be naïve to think these concerns are not present among engineering students.

There is clearly however no single approach to embedding reflective practice. A structured approach with a clear plan to guide students on reflection may help give them some technical confidence to understand their own weaknesses and potential growth areas however more subtle approaches may need to be used to breakdown the more personal sharing and critical review aspects which may hold some students back.

An area not fully explored in the survey was the longer term impact of reflective practice on students and into their graduate lives. Earlier work with graduates (Thomson (2019)) suggested reflective practice is valued once in the workplace - *"CDIO is a big part of my daily work day. It gave me the foundations of skills in working through projects. I still do weekly reflections on how my week has gone and what I should work on to improve."*. This too suggests that a fuller study on the efficacy of reflective practice could and should be looked at in more detail.

There is therefore future work which can be done to develop both reflective learning implementation strategies and appraise the longer impact on the growth of students and graduates.

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WHO AM I LEARNING TO BECOME? INTEGRATING PERSONAL DEVELOPMENT IN CURRICULUM DESIGN

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ABSTRACT

In this case study, we answer the question: what are design characteristics for a personal development line integrated in undergraduate engineering curricula? We investigated the development of such a line in a Bachelor of Architecture, Urbanism and Building Sciences in The Netherlands. We documented and analysed the preparation of and discussions during three design sessions, where teachers and students collaboratively created the personal development line.

This personal development line has two main aims: to guide students in developing their personal and professional identities and promote self-directed learning in the curriculum. Reflective skills are playing a key role in this. Four levels on which students reflect in relation to personal development in the curriculum were identified: self, education, practice, and society. Each Personal Development Week in the design proposal touches upon one of these levels and makes use of three generic elements: inspiration, contemplation, and perspective.

Three tensions in the curriculum arose during the design sessions. First, the question if it is necessary to give students direction by assignments or to trust they will reflect by themselves. Second, if that direction should be shaped by specific writing assignments or if students should be left to work with a free form. Finally, if the reflection should be connected to what students learn inside the university or rather to societal challenges that they perceive outside of their studies.

The personal development line in this research is one answer to the questions arising from these three tensions, yet it is not the only answer. Both the identified tensions and the designed reflection model can be a starting point for other curriculum designers to position personal development in their curriculum. Personal development can then become a key ingredient in the education of a diverse group of reflexive engineers at universities anywhere in the world.

KEYWORDS

Curriculum development, personal development, self-directed learning, reflection, reflexivity, standards: 2, 3, 7, 9, 11

INTRODUCTION

There is not one kind of engineer. Undergraduate engineering curricula need to be flexible enough to educate different personal and professional identities. Increasingly, universities try to offer inclusive education with awareness of their students' backgrounds (McKenna et al., 2014). Furthermore, the world expects engineers to be self-critical and equipped with the critical thinking skills necessary for the transition to a sustainable society (Wals, 2010). Therefore, students need to learn to reflect on their personal development during their education.

The CDIO approach (Conceiving – Designing – Implementing – Operating), an innovative engineering education framework, integrates reflection in their key features (Cheah, 2022). The approach is based on the idea that students learn the fundamentals of engineering through experience with real-world systems, products, processes, and services (Malmqvist et al., 2019). Students need to be equipped with reflective skills to learn from those real-world experiences. Different reflection methods exist for addressing personal development in individual courses, yet we know little about the use and effect of reflection in curriculum as a whole (Ebomoyi, 2020).

In this case study, we research the question: what are design characteristics for a personal development line integrated in undergraduate engineering curricula? We investigated the development of such a reflective line in the Bachelor of Architecture, Urbanism and Building Sciences at Delft University of Technology in The Netherlands. Based on an analysis of the Intended Learning Outcomes related to reflection, a design brief was defined for this programme by the Education Management. Additionally, we documented and analysed three curriculum design sessions, where teachers, educational advisors and students collaboratively created the personal development line.

THEORETICAL BACKGROUND

Reflection is a specific form of thinking (Dewey, 1910). Not only is reflection crucial to learning in general, but it can also be learned. It is this specific form of 'academic reflection' that we focus on in this paper and that can also be called 'metacognition' (Cunningham et al., 2015). Within the CDIO network, Cheah (2022) proposes to clarify the language for reflection and refers to this definition of Moon (2001) as a guideline: "Reflection is a form of mental processing – like a form of thinking – that we use to fulfil a purpose or to achieve some anticipated outcome. It is applied to relatively complicated or unstructured ideas for which there is not an obvious solution and is largely based on the further processing of knowledge and understanding and possibly emotions that we already possess."

Although reflection is a cognitive skill used in everyday life, it has a specific function in education. Academic reflection involves a consciously stated purpose that gives direction to the reflection (Moon, 1999). Through reflection, learning on personal and professional level can be made explicit, where it would otherwise remain implicit. This way, reflections can provide evidence of learning that could be used for assessment as well as for self-directed learning. Students undertaking self-directed learning take control of their own learning by making use of the flexibility in the curriculum to, for instance, choose electives, paper topics, or challenges that fit their ambitions (Brockett & Hiemstra, 1991).

In higher education, the evidence of reflection is predominantly collected as reflective writing. Particularly in experiential courses, reflective essays, papers, and reports are increasingly used as assessment methods (Kirk, 2017). These reflective assignments which require a personal voice should be clearly distinguished from essay writing on a scientific topic that aims to develop a logical argument (Nesi et al., 2021). To scaffold students towards reflective writing, Ryan and Ryan (2013) developed the 4Rs model (Reporting, Relating, Reasoning, and Reconstructing) for teaching and assessing reflection in higher education, which is often used as backbone for reflection assignments in higher education.

Most scholars describe reflection as a process with different deepening layers (Bain et al., 2010). The 4Rs model, for example, asks students to connect their individual experiences to literature and incorporate the perspectives of others in their writing. Students not only 'describe' what they experienced, they also 'compare' and reframe the matter through the eyes of others (Jay & Johnson, 2002). Ultimately, this can lead to a critical reflection, where students create an alternative perspective based on renewed insights.

In (architectural) design education, students learn reflection mostly in the design studio. Design expertise is being built through constant reflection on the object that is being designed (Lawson & Dorst, 2009). The work of Van Dooren et al. (2013) describes the generic elements that architecture students discussed while learning to design. Although reflection is integrated in the way students learn to design, we do not know to what extent students can transfer the skill of reflection on their design object to reflection on their personal development.

In this compact overview of the literature, two important things stand out. First, although many different reflection tools exist in practice, reflection assignments in higher education focus on writing, and in design education on the designed objects. Second, those reflection assignments are connected to the learning process during one course but rarely extend to include the development of students within an entire curriculum. Therefore, we explore how reflection can be incorporated through the curriculum as a whole and which learning objectives can be achieved aimed at the personal development of students.

METHODS

We investigate the development of a personal development line in the Bachelor of Architecture, Urbanism and Building Sciences at Delft University of Technology in The Netherlands. Based on an analysis of the Intended Learning Outcomes related to reflection, a design brief was defined for this programme by the Education Management. We document and analyse three curriculum design sessions, where teachers, educational advisors and students of the faculty collaboratively create proposals for the personal development line. Our approach is based on educational design research. Plomp and Nieveen (2014) define design research in an educational context as follows: "To design and develop an intervention (such as programs, teaching-learning strategies and materials, products, and systems) as a solution to a complex educational problem as well as to advance our knowledge about the characteristics of these interventions and the processes to design and develop them, or alternatively to design and develop educational interventions (about, for example, learning processes, learning environments, and the like) with the purpose to develop or validate theories." (Plomp & Nieveen, 2014, p. 15)

This design research looks at the personal development line as a solution to the complex educational question of how to guide students in developing their personal and professional identities. In this process, we aim to find characteristics from the personal development line to advance our knowledge of self-directed learning. Additionally, we document the tensions and challenges that teachers and students discuss while designing the personal development line.

RESULTS

Intended Learning Outcomes related to reflection

Starting point of the educational design process was the analysis of the Intended Learning Outcomes of the Bachelor Programme, looking from the perspective of reflection and of personal development. The Intended Learning Outcomes are divided in seven groups, of which two groups are the most important for this topic: temporal and cultural context, and academic attitude. Within these two categories seven Intended Learning Outcomes were found that relate to reflection and personal development:

<u>Temporal and cultural context</u>
- The student has an ethical-professional understanding and can reflect on the role and position of the field of architecture in society.
- The student can critically reflect on him/herself as a construction engineering student and on the processes and products of study.
- The student can assess the position of the designer, the engineer, the planner and the manager of the built environment within the field of private and public parties and the civic society.

<u>Academic attitude</u>
- The student is independent and has the ability to ask and discuss relevant questions.
- The student has a critical-reflective attitude toward science, engineering, research and design.
- The student can take a considered position in design situations.
- The student can argue persuasively and in a well-structured manner.

Design brief for the Personal Development Weeks (PDW)

These Intended Learning Outcomes were already being addressed in various design, research and skills courses, but in a rather implicit way. Therefore, the Education Management proposed the first outline of a personal development line, consisting of five Personal Development Weeks (PDW), spread across the curriculum: halfway each semester of the three-year Bachelor Programme (the P's in **Figure 1**).

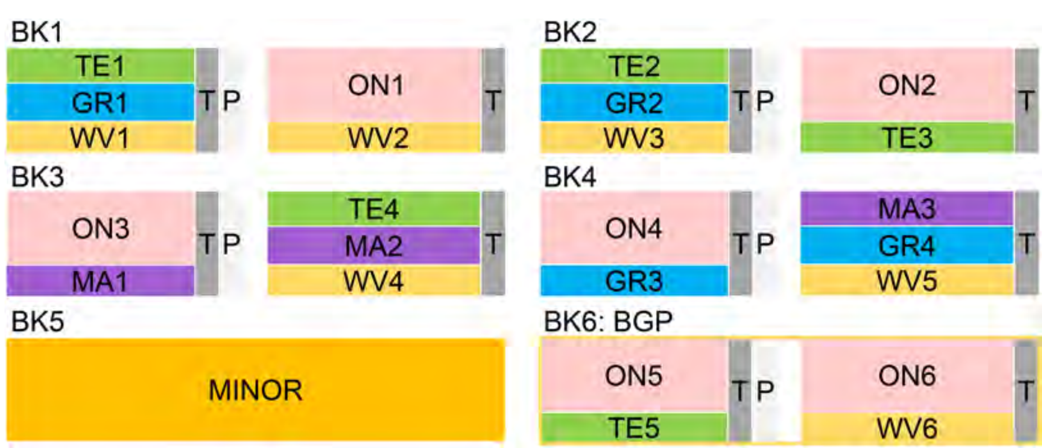

Figure 1. Proposed re-design of the Bachelor Programme in Architecture, Urbanism and Building Sciences, with 6 learning trajectories: ON Design (6*10 ECTS), WV (Science and skills) (6*5 ECTS), TE Technology (5*5 ECTS), GR Fundamentals (4*5 ECTS) and MA Society (3*5 ECTS); T = assessment weeks; P = Personal Development Weeks.

The PDWs were given the following starting points for the design sessions:

- PDW assignments might have a free form.
- A PDW will have no teaching hours, but only one small reflection assignment to be made.
- A PDW will not lead to separate ECTS's, but the five assignments will be part of the last course of the Science and skills trajectory (WV6) in the Bachelor Graduation Project (BGP).
- PDW assignments will be assessed in this WV6 course, but they will also start the group discussion in the course that immediately follows every PDW.
- For the PDW assignments it is being proposed to deepen and enrich reflection through the programme, based on four levels on which students can develop their personal and professional identities: self, education, practice, and society (see **Figure 2**).

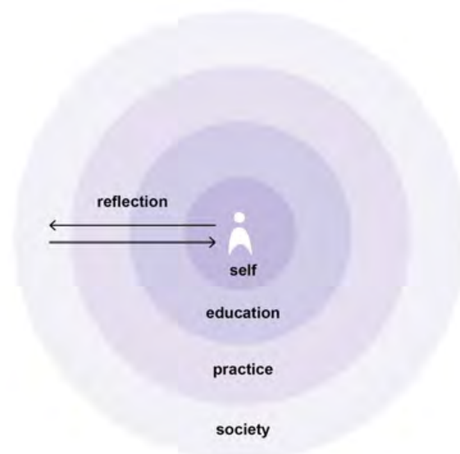

Figure 2. Four levels (self, education, practice, and society) on which students can develop their professional and personal identities. Reflection as part of the curriculum allows students to switch between these levels.

Design sessions for the Personal Development Weeks

The Intended Learning Outcomes and the design brief formed the starting point for three design sessions with teachers, educational advisors, and students. We organized one exploratory workshop (design session 0) with reflection experts from several other higher education institutes to refine the design brief before the PDW design team started (see **Table 1** for an overview of the sessions and themes). In the next paragraph, we will describe the design proposal that resulted from these sessions.

Table 1. Themes of the design sessions between November 2022 and April 2023.

Design session	Dates	Theme
Design session 0	November 16	EXPLORE - What do the concepts of reflection and personal development entail?
Design session 1	February 7	START - What do we already know about reflection and personal development in our current curriculum?
Design session 2	March 9	AIMS - What are we aiming for?
Design session 3	April 6	ACTIVITIES - What are the reflective activities we envision to use in the personal development line?

The design proposal of the Personal Development Weeks

A personal development line spread over three years

There are five PDWs in the three-year Bachelor Programme: two in each of the first two years and one in the final year. The design team agreed that every year should have a specific focus. Year one could focus on the transition from high school to university student and the hopes and dreams that belong to the start of university education (self). At the same time, the first-year PDWs should address the practical and content-related side of being a university student, such as time management, cooperating in teams, dealing with feedback, and getting familiar with learning styles and with the fundamentals of the discipline (education). A central role for student tutors was proposed in the first year, for instance in the form of peer guidance and review. In this first year, the PDWs should contribute to community building within the student cohort, as this will keep students motivated throughout the curriculum.

In year two, the PDW will stimulate students to reflect on their development as designers within the discipline (practice). As the PDWs in the second year are scheduled after the design studios (ON courses in **Figure 1**), they offer an ideal opportunity to reflect on the experiences from the studio and prompt questions such as 'what kind of designer am I?'. The PDWs will also focus on career orientation. As such, the PDW should be aligned with the information meetings for the Master Programmes.

The third year focuses on making connections to societal challenges (society). Assignments will evolve on defining a position in the entire spectrum from self to society. The question can be raised how reflection can lead to action: who am I and what role can I play in society?

Three generic elements in each Personal Development Week

The design team aimed at activities to be largely self-defined by students and to be taking place outside of the familiarity of the campus. For instance, students could be asked to go outside, to walk, to visit museums, or go on excursions. In addition, relevant workshops or lectures can be organized on-campus. The team had different opinions on how concrete the assignment should be: from prescribed to completely free assignments. Ideas for forms could be journals, videos, posters, infographics, sketches, or even songs and spoken word.

Nevertheless, three generic elements were proposed for each of the five PDWs: inspiration, contemplation, and perspective. Although they do not correspond to specific learning objectives that are being assessed within the PDWs, these three generic elements do describe the aims that the design team had for the personal development line as a whole.

First, inspiration arose from a wish of both students and teachers to have time to explore interests that are not part of the core curriculum but do relate to the discipline. Furthermore, it is important to know what you will be reflecting on in the PDWs, and in that sense, inspiration can also come from looking back at experiences from other courses.

Second, contemplation refers to both the active reflection on inspiration and other experiences, as well as the wish to 'rest'. In this case, rest does not mean holiday, but it does mean to be in a different mental space than during the regular curriculum.

Third, students will look ahead at what is next. The step of creating perspective, for instance by formulating personal learning goals, is crucial to self-directed learning. This is the moment in the week where students will be able to take all the insights they have gained and transform them into calls for action.

A common starting and finishing point for the curriculum

The introduction of the PDWs requires a different approach to education. The activities need to speak to the intrinsic motivation of the students to explore their personal development. From the assessment point of view, the design brief stated that the products of the five assignments will be part of the last course of the Science and skills trajectory (WV6 in **Figure 1**). To emphasize the importance of the PDWs right from the start, they will need a thorough introduction in the first Science and skills course (WV1 in **Figure 1**). Furthermore, the design team proposed the first day of the first year of the bachelor as part of the personal development line (**Figure 3**). During this day, students will get familiar with reflection tools for personal development and touch upon some of the key themes of being a first-year student at university.

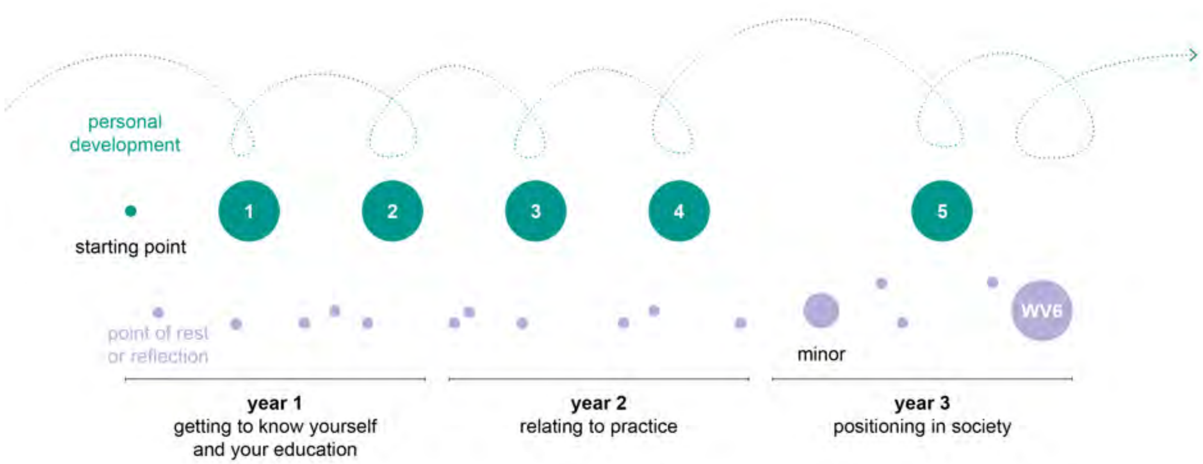

Figure 3. A visualisation of the Personal Development Weeks created by the design team. It shows both the personal development line (green), as well as a suggestion for the points of rest and reflection in other courses (purple).

DISCUSSION

The curriculum design sessions revealed several tensions. Three of those tensions resurfaced more frequently in the design team's discussions and we consider them to be significant for others who work on methods for reflection and personal development in undergraduate engineering curricula.

The first tension is that between designing a full reflection assignment and the option to not design anything and leave the weeks for personal development completely empty in the schedules of students and teachers. Could the necessary reflection be achieved equally well outside the curriculum and the faculty building as within?
The answer formulated by the design team is 'no'. Free time outside of the curriculum is not automatically being spent on personal development. Getting grip on that personal development is deemed crucial for self-directed learning in the rest of the curriculum.
Second, the design team was confronted with ideas of what education traditionally should look like. Self-directed learning puts some responsibilities on the student that used to be with the teachers. Should the reflection assignments be specified tasks with a well-defined outcome, or will the reflection benefit from an assignment with a free form?

Some general considerations were made during the design sessions. The general opinion was to make the assignments (very) small. At the same time, students should not have the idea that there is only one 'nasty' task to do in a week that is meant to recuperate; this is considered a complicated tension. Therefore, the assignments should be formulated in a positive way, with – especially in the first year – a clear relationship with the following course. This makes it necessary that the teachers of those courses are well-informed of the PDW assignment and its use and role in the curriculum.
Finally, we noticed a tension between relating the PDWs to the specific preceding courses, or to the personal development of the students in general. Will the reflection assignments increase in value for the students if we give them the opportunity to address present societal challenges, such as sustainability or health?
The design proposal suggests leaving the assignments open both in form and content, so students can follow their own inspiration. However, in the second and third year, the aim to relate to design practice and society should be made explicit.

There is not one answer to these tensions that applies to every undergraduate engineering curriculum. However, those interested in using reflection as an explicit part of the curriculum can use these tensions as starting points for their discussion.

CONCLUSION

Students get to know their engineering identity and future role in society by reflecting on their personal development throughout the curriculum. In this paper, we researched the design of a personal development line on curriculum level that aims to guide students in developing their personal and professional identities and promote self-directed learning.
This educational design research focused on the analysis and design brief for a personal development line in an undergraduate engineering curriculum in the Netherlands and on the design team of students, educational advisors and teachers elaborating this programme. The starting point was a personal development line of five Personal Development Weeks, based on four levels of reflection: self, education, practice, and society.
In the design proposal, each Personal Development Week touches upon one of these levels. Additionally, every week makes use of three generic elements to offer students guidance in the process of reflecting: inspiration, contemplation, and perspective. The personal development line has a common starting point on the first day of the academic year for all first-year students to get familiar with reflection tools for personal development and touch upon some of the key themes of being an academic. As the line encompasses more reflective levels over time, it asks students to reconsider their position based on new insights they gain. The first weeks focus on the students themselves and the way they learn, and then the PDWs gradually shift to comprise their professional career orientation and role in society.
Throughout the design process, three characterizing tensions arose. First, the question if it is necessary to give students direction by assignments or to trust they will reflect by themselves. Second, if that direction should be shaped by specific assignments or if students should be left to work with a free form. Finally, if the reflection should be connected to what students learn inside the university or rather to societal challenges that they perceive outside of their studies. The personal development line in this research is one answer to the questions arising from these three tensions, yet it is not the only answer. We hope that by making these tensions insightful for other curriculum designers, they might find their own way of navigating them towards a more reflective and flexible curriculum.

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ENTREPRENEURSHIP IN ENGINEERING PROGRAMS: A METHODOLOGY FOR SYSTEMATIC LITERATURE REVIEW

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ABSTRACT

Understanding and implementing educational approaches that integrate entrepreneurship and innovation in engineering education (CDIO Syllabus 4.1, 4.2, 5.2) plays a pivotal role as part of Technical University of Catalonia's (UPC) core strategic plan for the upcoming years. In engineering programs, educational models have evolved from teacher-guided to more ”real world”, challenged-based practical approaches (CDIO Standard 5) which increases the likelihood of engineering students becoming entrepreneurs. Scholarly research that assesses the validity of these new pedagogical models or that measures entrepreneurial throughput in a country is constantly growing, which makes staying up-to-date with relevant academic work an arduous task. Moreover, several systematic reviews have highlighted the shortcomings of traditional methodologies to synthesise primary studies in engineering education in this regard. We put forward a three-step methodology using mining techniques and statistical software that allows for a more refined identification of papers, with two improvements for a systematic review: 1) automatically identifying extended keywords and 2) ensuring relevant studies are not discarded, with a second iteration. We tested this methodology with literature of the last three decades, with a focus on papers that measure outcomes in engineering education. The initial results of our study revealed that surveys are the predominant measurement tool utilised to assess entrepreneurial skills, traits, intention, or mindset. However, there is a lack of agreement in the existing literature on the definitions of these terms. Furthermore, these initial results suggest the need for additional methods of measuring outcomes in Engineering Entrepreneurship programs.

KEYWORDS

Engineering Education, Entrepreneurship, Systematic Review, Outcomes Measurement, Standards: 5,12

INTRODUCTION

The integration of entrepreneurship and innovation within the realm of engineering education in higher education institutions worldwide is receiving much attention lately. As the field of engineering education continues to evolve towards more practical, implementing more real-world pedagogical approaches, it becomes increasingly important to comprehend and integrate models that foster entrepreneurial mindsets among undergraduate and graduate students. Scholarly research that assesses the validity of these new educational models or that measures entrepreneurial throughput in a country is constantly growing, which makes staying up-to-date with relevant academic work an arduous task. Moreover, several systematic reviews have highlighted the shortcomings of traditional methodologies to synthesise primary studies in engineering education.

In the CDIO knowledge library, there are several papers about approaches to promote innovation and entrepreneurship skills in engineering graduates; some of these papers describe long term actions and include measurement indexes as improvement of the employment rate (Kallio-Gerlander, Puhakainen, & Kettunen, 2013) or describe the results of several initiatives (Hallenga-Brink, 2017). Bibliometric studies have also been performed in the CDIO community. Meikleham, Hugo, and Aldert (2018) visualised the evolution of CDIO influence in the field of engineering education since 2000 including the journals and conference proceedings available in Scopus and Web of Science. Malmqvist, Machado, Meikleham, and Hugo (2019) analysed the historical and geographical trends over time of the conference paper publications available in the CDIO Knowledge Library which are, however, not included in Scopus and Web of Science.

The goal of this paper is to propose a three-step methodology that builds on top of traditional methodologies for systematic literature reviews in engineering education (Borrego, Foster, & Froyd, 2014). We use this methodology to cluster and identify studies from two different databases that evaluate the outcomes of entrepreneurship education in engineering studies and to explore the ways in which these outcomes measurement methods are conducted (e.g. surveys). We make use of text mining techniques and statistical software that allows for a more refined identification of papers, with two improvements for a systematic review: 1) automatically identifying extended keywords and 2) ensuring relevant studies are not discarded, with a second iteration. We tested this methodology with literature of the last three decades, with a focus on papers that measure outcomes in engineering education when there are entrepreneurship and innovation programs in place. This approach allowed us to identify the fundamental theories, themes, and constructs used in prior research, and also to examine how the research design and the tool selected shapes the interpretation of the value of entrepreneurship education and the research findings. In addition, it also allows us to better understand the ways in which entrepreneurship education has been evaluated and the potential limitations and biases present in the existing literature.

LITERATURE REVIEW

In this section, we examine the different methodologies employed in previous systematic reviews on the topic entrepreneurship in engineering. This review includes literature from the field of engineering education as well as literature that pertains to novel approaches in performing systematic searches.

The first study that is relevant for the present study is Borrego et al. (2014). In their systematic review of systematic reviews in engineering education, they proposed a step by step methodology for conducting reviews in this area by adapting procedures that were initially designed for other disciplines. Their methodology has been widely applied in the recent literature and has, as well, served as inspiration to our methodology. Huang-Saad, Morton, and Libarkin (2018) also used this approach to conduct a systematic literature review examining the state of the art in engineering entrepreneurship education in 2018. The scope of their review was broader than the present study, as it included disciplines beyond Engineering, however. According to the authors ”outcomes are often not aligned with engineering outcomes, or assessment instruments have shown to be invalid for engineering students” which calls for a reevalution of these assessment practices in engineering (Huang-Saad et al., 2018, p.284). Similarly, Cruz, Saunders-Smits, and Groen (2020) conducted a systematic review focusing on the state of the art in competency measurement methods for assessing Engineering students' mastery of skills such as innovation/creativity, communication, lifelong learning, and teamwork in higher education. Although their review was specific to engineering education, it was not limited to entrepreneurship and innovation assessment. They identified measurement tools used by educators and researchers which lacked validity and that called for more standardised methods. The last study that is relevant for our paper is Grames, Stillman, Tingley, and Elphick (2019), who conducted scientific literature review using a reproducible method that employs text mining techniques to avoid bias in the search strategy and ensure the inclusion of all relevant keywords. This method, however, was tested in the fields of ecology, evolution, conservation biology, and related disciplines, but not in engineering education to the best of our knowledge.

In recent years, the methodology for conducting systematic literature reviews within the field of engineering education has gained significant attention and undergone significant refinement, although it remains in its nascent stage (Borrego et al., 2014). The present study departs from traditional methodologies in order to conduct a more comprehensive examination of the existing literature pertaining to a specific topic (i.e. outcomes measurement methods) within engineering education. The current study aims to identify various measurement methods in engineering education and evaluate the entrepreneurial activity reported in the existing literature using a new search methodology. To guide this review, the following research question is formulated: Does the three-step methodology proposed in this study enable the identification of relevant publications on entrepreneurship in engineering education that may be overlooked by traditional search methods?

METHODOLOGY

As has been shown, systematic literature reviews and their associated methodology have acquired widespread acceptance and the numerous publications in the literature have made significant contributions to further research on assessing the outcomes of entrepreneurship and/or innovation programs or subjects in engineering programs. However, these reviews can sometimes struggle to keep pace with the rapid progress of research in this area. To address this challenge, new approaches that partially automate the process through the use of text mining techniques may increase efficiency and reduce the time and resource costs associated with conducting such reviews. In the following paragraphs we provide a detailed description of the three-steps methodology proposed, taking Borrego et al. (2014)'s methodology as a foundation and adapting Grames et al. (2019)'s mining techniques to engineering education; we also added semantic analysis and used a statistical software to make sure the search identified all the studies that were relevant for our purposes.

The starting point for our naive search was a combination of different keywords we would expect to find in the title, abstract or authors' keywords in all the studies included in our systematic literature review. We ran our initial search query in two databases: Scopus (primarily focused on indexing science, technology, medicine, humanities, social sciences and art publications)

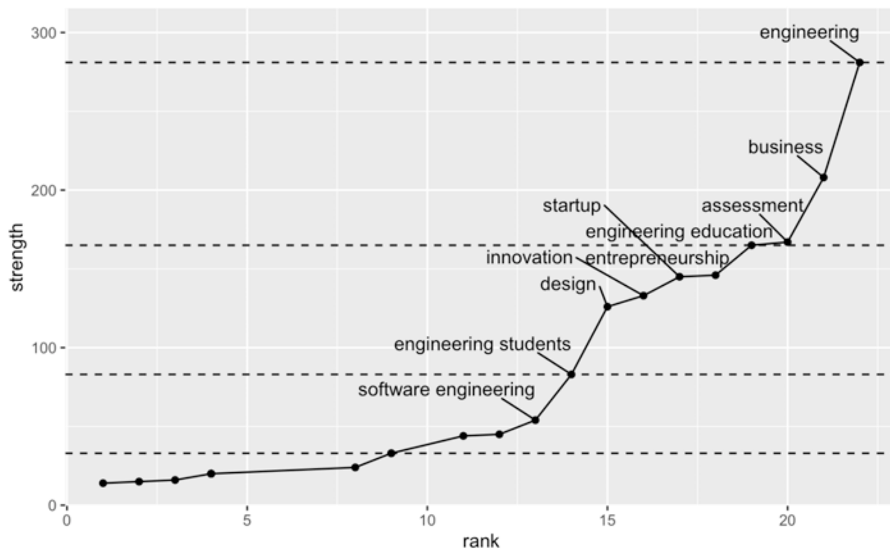

Figure 1. Strength of the top keywords found on first naive search.

and Web of Science (primarily focused on indexing social sciences, humanities and art publications). As a result, 64 and 17 studies were identified on each database respectively with 12 duplicates, after querying for ”engineering education”, ”measure / assess / evaluate”, ”innovation / entrepreneurship, and ”start-up”. We subsequently searched for potential keywords, in title, abstracts and also considering authors’ keywords. After applying semantic analysis techniques that included removing stopwords and tokenising terms, not only considering single words but also bigrams and trigrams, we ranked them based on their strength. In other words, we ranked each term in the network based on the number of other terms that it appears together with; that is, the more strength a term has, the more interesting to be included in a new search query. Our results are displayed in Figure 1 where only the top terms are labeled, together with different change points using dashed lines representing where there is a greater difference between contiguous values.

Expanded search: step one

After conducting a thorough review of the previous research found, we identified three additional key terms, namely ”business”, ”design”, and ”engineering students”, that were not included in our initial query. As a result, we added these terms to our query and grouped them as follows: *(”engineering education” OR ”engineering students”) AND (measure* OR assess* OR evaluate* OR design*) AND (innovat* AND entrepreneur*) AND (start-up* OR business*)*. On January 10th, 2022, we performed the last search utilising Scopus and Web of Science and identified a total of 1010 and 279 citations, respectively. Upon removing duplicates, we were left with a final pool of 1137 citations to be screened. It is important to note that our search was limited to English language publications in journals and conference proceedings which are indexed in the mentioned databases, with no restriction on publication year; they were all published in the last three decades, however.

Screening: step two

The next step involved a screening process to determine the final sample of publications for examination in the present study. To achieve this, we established a set of inclusion criteria for publications to be considered in our final sample. Firstly, we only included publications that focused specifically on engineering students in formal higher education institutions. As such, publications discussing broader, non-specific programs or institutions were excluded, as were publications discussing alumni or students at lower education levels. Additionally, publications not strictly related to engineering education were also excluded, as they often encompassed other types of higher education programs such as business studies. Finally, publications involving actual business stakeholders in the entrepreneurship or innovation programs were excluded to limit the present study to situations where engineering students are solely responsible for the business idea and not just contributing from a technical standpoint. Secondly, we included all publications that described the implementation of entrepreneurship and/or innovation programs aimed at providing engineering students with the necessary competencies for entrepreneurship and innovation. Specifically, only intervention studies were considered while characterisation studies were excluded. Additionally, publications that only examined a particular skill or knowledge such as Agile Development, Design Thinking or Project Management were not considered, as well as publications that did not describe any intervention on entrepreneurship or innovation programs at a higher education institution since they centered their study on assessing entrepreneurial mindset or intent using variables such as gender, social background, type of engineering, or student grades among others.

In order to establish the final sample of publications for examination in the present study, a thorough screening process was employed. This process entailed a comprehensive evaluation of the title, abstract, and authors' keywords (when available) of each publication. Additionally, a semantic analysis was conducted to identify relevant keywords in context. To aid in this process, R programming language was utilised to extract keywords through the utilisation of techniques such as stemming, stopword removal, and keyword combination. As a result of this screening process, a final list of 183 publications were selected for analysis in the subsequent sections of the study. Upon completion of the screening process, the final sample of publications to be analysed was grouped and presented per publication year in Figure 2. A visual examination of this figure reveals a higher representation of the targeted publications within the most recent 5-10 year period.

Network analysis: step three

In order to identify potential relevant papers that were either discarded during the screening process or were not identified in the final query across the previously mentioned databases, we conducted the final portion of the methodology using the 183 publications obtained. Upon verifying the availability of Digital Object Identifiers (DOIs) via lens.org, we found that only 120 of the citations had DOIs. utilising the R package developed by Haddaway, Grainger, and Gray (2022), we extracted both the publications that were referenced in our bibliography and those publications that cited our bibliography. The resulting network visualisation of publications with frequency greater than or equal to five, as depicted in Figure 3, illustrates the size of the node being directly proportional to the number of citations the publication has received, and distinguishes between references represented in red and citations represented in blue.

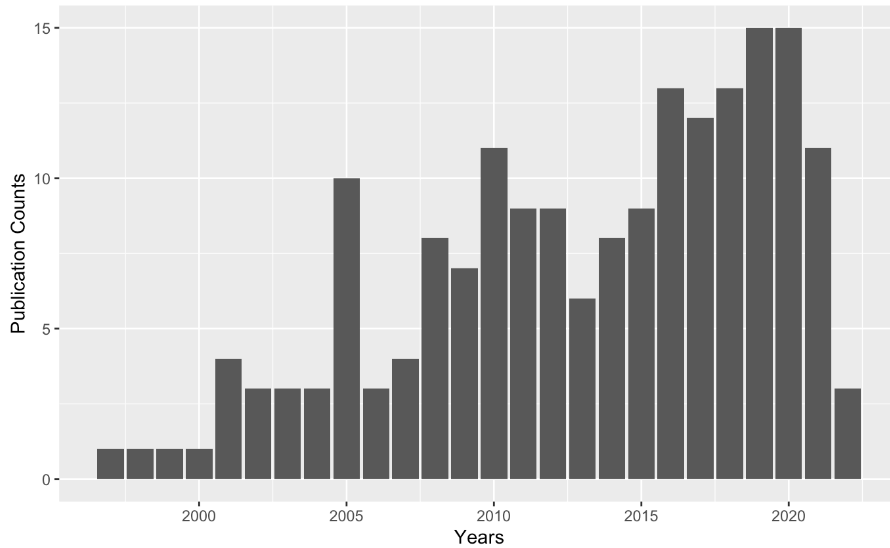

Figure 2. Screened publications (n=183) subject to analysis, grouped per publication year.

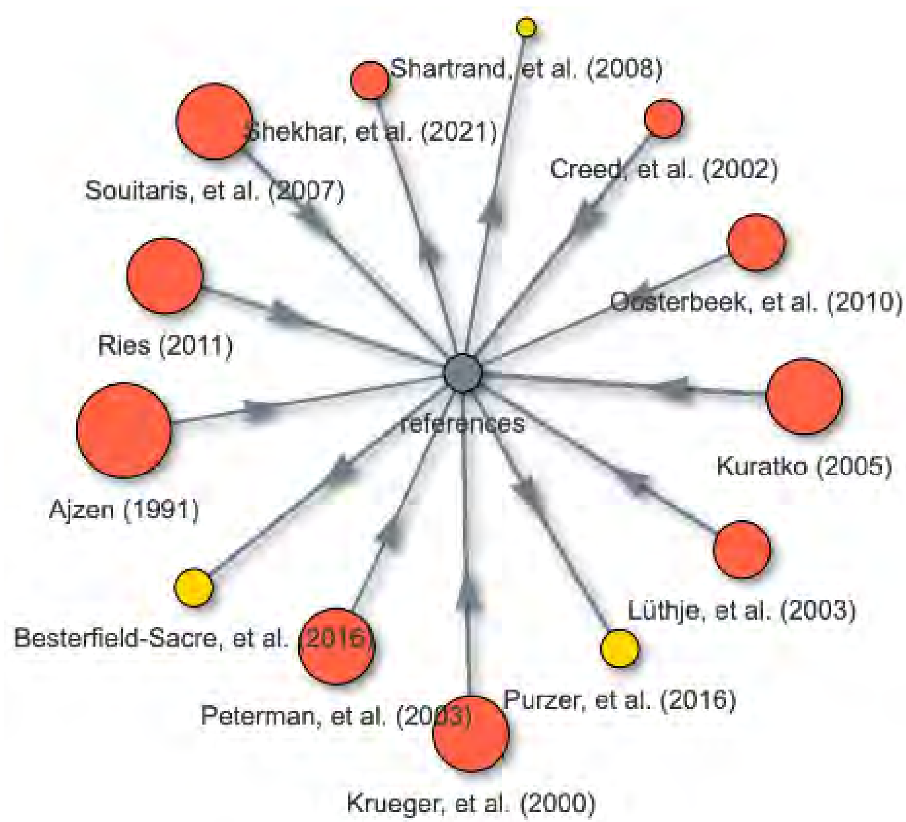

Figure 3. Network representation for references and cites with >5 appearances in our sample.

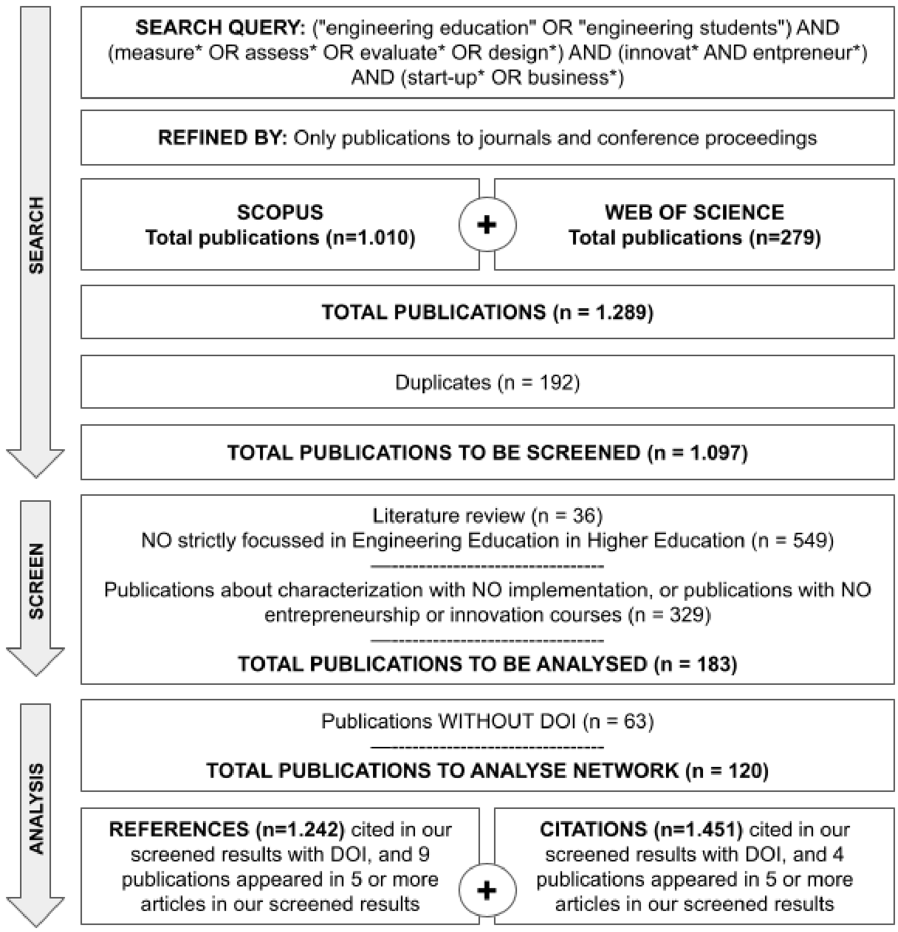

Figure 4. Summary of the methodological approach

A summary of the complete methodological process described in this section is depicted in Figure 4, starting from the expanded search to the network analysis. In the following section of this study, we investigate the suitability of the most highly ranked references, based on citation count for our research focus, which specifically examines the use of interventions in engineering education to promote entrepreneurship and innovation. We also consider the type of program and evaluation methods employed.

The subsequent section of this study evaluates the appropriateness of the references that have received the highest citation counts for our research focus, as a preliminary examination of the methodology proposed in this study.

RESULTS AND DISCUSSION

We now report the preliminary examination of the methodology proposed for the development of a comprehensive systematic literature review on the topic of interventions in engineering education to promote entrepreneurship and innovation. For this paper we selected the most relevant publications (10), ranked by citations, from the expanded search results, as well as an equal number of publications obtained through network analysis of both references and ci-

Table 1. Summary of the reviewed publications

Categories	References (10)	Broader Search (10)	Citations (10)
Engineering Education	4	9	10
Intervention	2	5	3
Entrepreneurship program described	2	5	1
Outcomes measurement			
Qualitative interviews	1	2	
Surveys, entrepreneurial intentions	1		1
Surveys, entrepreneurial skills		4	

tations. The study specifically investigates the use of interventions in engineering education to foster entrepreneurship and innovation, and also focuses on evaluating the presence of entrepreneurship and innovation programs, as well as any methods of program evaluation employed, such as surveys or interviews. In Table 1 the results of these publications reviews are tabulated, differentiating when each set of publications were retrieved.

The reviewed literature that meets the purpose of this study reveals that the majority of the publications that are centered in describing a given intervention in engineering education degrees where a program in entrepreneurship and / or innovation has rolled out, just consider a few different ways of assessing the program. Surveys, both pre and post course, are widely used as in Bellotti et al. (2013) where authors describe the use of surveys to assess entrepreneurial skills, although with no conclusions as they did not process the data. Also, in Bilén, Kisenwether, Rzasa, and Wise (2005) and Wang and Kleppe (2001) the authors complement data coming from students' surveys, with additional qualitative data from interviews, but in both cases still centered on assessing entrepreneurial skills. Additionally, the same trend of outcomes measurement has been used in the existing literature to correlate the results of positive measurement on entrepreneurial skills with higher grades and higher rate of students' retention Ohland, Frillman, Zhang, Brawner, and Miller III (2004). On the other hand, in Joseph (2013) and Souitaris, Zerbinati, and Al-Laham (2007) authors, in both cases, use surveys to assess their entrepreneurship programs, but this time with a focus in entrepreneurial intentions rather than skills and using, in the case of the latter, some survey adaptations from previous studies in the literature. Lastly, in Creed, Suuberg, and Crawford (2002) the authors center their measurements in the use of qualitative students interviews. They concluded that "the ultimate success story would be to see one of these student's companies spin off as a real company" (Creed et al., 2002, p.194), which is probably one of the key metrics to incorporate to the previous outcomes measurement methods that would count with major consensus; not being immediately available is its main drawback, however.

CONCLUSIONS

As seen in Figure 2 there is a growing body of literature over the recent years and, for this reason, we aimed to provide a three-step methodology that builds on the existing methodology to conduct systematic literature review of studies that focus on engineering education, as in Borrego et al. (2014), so that our research in the field keeps pace with the production of academic texts on the topic. Our methodology allowed for a better search in that, through an expanded search, new keywords related to the main topic were automatically found. Additionally, through a second iteration, our proposed methodology identified studies that would otherwise have been lost in the search. Our reviewed publications revealed that most of the measurement tools are based on surveys to assess entrepreneurial skills, traits, intention or mindset, with no common consensus in the existing literature on the definition of each concept (Huang-Saad et al., 2018), and that additional outcomes measurement methods for Engineering Entrepreneurship programs are also required (Creed et al., 2002).

It is important to highlight the limitations of the present study. First, rather than providing an exhaustive systematic review of the literature, this paper aimed to highlight a new methodological procedure to undertake a systematic review of studies centered in entrepreneurship in engineering education. Second, even though the literature is all related to engineering education, the terminology may vary; in this regard, authors may make a different use of the same terminology. This idiosyncratic use of terminology may have affected the results of the search presented in this paper and would require a manual, deeper analysis of the studies found; it also calls for peer-review processes to reach greater consensus. It would be interesting to apply our methodology to complete the systematic literature review not limited to the publications with most citations; this would perhaps allow to find papers that put forward different outcomes measurement methods for entrepreneurship and innovation programs in engineering education. Moreover, this methodology can be extended to other domains of inquiry, potentially encompassing additional CDIO standards, such as program assessment (CDIO Standard 12), where it is usually needed to perform literature reviews with a view of finding out what is being done in other institutions in a given area of focus.

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APPENDIX

Table 2. Complete list of reviewed publications.

	Publications	EE	IN	EP	MM
References	Krueger, Reilly, and Carsrud (2000)				
	Souitaris et al. (2007)	x	x	x	Surveys, entrepreneurial intentions.
	Creed et al. (2002)	x	x	x	Qualitative interviews.
	Peterman and Kennedy (2003)				
	Bird (1988)				
	Lüthje and Franke (2003)	x			
	Kuratko (2005)	x			
	Oosterbeek, van Praag, and Ijsselstein (2010)				
	Ries (2011)				
	Ajzen (1991)				
Expanded Search	Bellotti et al. (2013)	x	x	x	Surveys, entrepreneurial skills.
	Bilén et al. (2005)	x	x	x	Surveys, entrepreneurial skills.
	Creed et al. (2002)	x	x	x	Qualitative interviews.
	Van Looy et al. (2011)	x			
	Vodă and Florea (2019)	x			
	Bellotti et al. (2014)	x			
	Wang and Kleppe (2001)	x	x	x	Surveys, entrepreneurial skills.
	Ohland et al. (2004)	x	x	x	Surveys, entrepreneurial skills.
	Maia and Claro (2013)	x			
	Tessema Gerba (2012)				
Citations	Cico, Jaccheri, Nguyen-Duc, and Zhang (2021)	x			
	Duval-Couetil, Reed-Rhoads, and Haghighi (2010)	x			
	Purzer, Fila, and Nataraja (2016)	x			
	Shartrand, Weilerstein, Besterfield-Sacre, and Olds (2008)	x			
	Prateek and Huang-Saad (2021)	x			
	Thompson (2012)	x	x		
	Besterfield-Sacre, Zappe, Shartrand, and Hochstedt (2016)	x			
	Hassan, LeBlanc, and Al-Olimat (2013)	x	x		
	Joseph (2013)	x	x	x	Surveys, entrepreneurial intentions.
	Celis Guzman (2015)	x			

Notes: EE = Enginnering Education, IN = INtervention, EP = Entrepreneurship Program, MM = Measurement Methods.

BIOGRAPHICAL INFORMATION

Saül Garcia Huertes is an assistant professor at Telecos-BCN, Technical University of Catalonia (UPC), where he lectures courses on innovation and entrepreneurship topics. He is currently a PhD candidate in the Education on Engineering, Science and Technology program at UPC, and his research interests include innovation and entrepreneurship education and experiential learning.

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CORRELATION STUDY BETWEEN THE PERFORMANCE IN DIFFERENT ENGINEERING COURSES AND PROJECT-BASED COURSES

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ABSTRACT

In a previous study, already published (Bragós, 2022), we analyzed the correlation between the University access mark to the engineering studies with the grades obtained in project-based courses and in non-project-based standard courses. A lower correlation with the capstone course performance (R=0.3) than the one obtained with the average of the other courses (R=0.6) was obtained. Probably as a result of the fact that a different kind of skills are promoted in these courses. In this paper, we have changed and extended the scope of the correlation study. We used as a reference of the students' performance index the individual average marks in the 1st year basic courses. Then we obtained the correlation with different categories of courses of our engineering program: theoretical/practical, mandatory/elective, by disciplines, and the Project-Based Learning (PBL) and Product Development Project (PDP) courses. This is, using internal indicators instead of the access mark, which has an external origin, and improving the granularity of the study. We have analyzed four consecutive cohorts that have completed a coherent set of subjects, n=762 students. We have classified the subjects (40 courses per student in average) in the categories aforementioned. They are compared with the performance in two "classic" PBL courses and a capstone PDP course. There is also a final Engineering bachelor thesis which is usually performed individually in companies or research labs. The very abridged results of the study display differences even higher that the ones obtained with the access mark. The three groups of non-project standard courses show a higher correlation among them (R=0.84 Basic to Mandatory-Disciplinary; R=0.69 Basic to Elective-Disciplinary) that when comparing the Basic courses with the PBL courses (R=0.59) or with the capstone PDP course (a very weak correlation with R=0.26). The complete set of cross-correlations among the categories is displayed in the paper. Like in the study about the correlation with the access mark, the main conclusion is the evidence that there is a remarkable set of students which have difficulties in the standard courses, with a higher analytic content but can perform very well in the project-based courses. Therefore, a different kind of skills are promoted in these courses. This is, in our opinion, a positive result because these students can find a place to stand out. It enhances their self-confidence and their perception of a potentially good performance in their future career.

KEYWORDS

Project-Based Learning, Product Development Project, Correlation Study, Standard: 5

INTRODUCTION

Project-Based Learning and, specifically, Product Development Project (PDP) capstone courses where student teams develop “real” projects using their theoretical knowledge on a system level (Dym, 2005), (Hoffman, 2014), are considered among the more successful tools to promote the personal, interpersonal and professional competences required by the different accreditation agencies and worldwide initiatives that have defined lists of skills. The CDIO community has a long record of capstone projects with external stakeholders. Design-Build projects (CDIO standard 5) are one of the most acknowledged ways of promoting the learning of skills of groups 2, 3 and 4 of CDIO syllabus (Crawley, 2011). From the very beginning of the Initiative, there have been papers describing the cooperation between academia and industry. Surgenor (2005), already described the involvement of industry in capstone projects at Queen’s University in Kingston, Canada. Berglund (2007) also describes a 4th year multidisciplinary capstone project with industry involvement carried out at Chalmers. Thomson (2012) compares two projects performed at Aston University with different openness degree in the starting brief and project follow-up. Hallin (2012) discusses the role of customers of both the industry and the students, which have a different time-perspective. Mejtoft (2015) discusses about the double role of Industry as enabler of collaborative projects and receiver of the developed results. More recent references describe the initiative to involve stakeholders at program level at DTU (Nordfalk, 2018), the review of university-Industry collaboration in Europe and Asia (Rouvrais, 2020) or the use of Communities of Practice to guide and support Capstone supervision (Topping, 2022).

There are evidences from observation by faculty members and from feedback from students that the kind of skills promoted in these courses require a different learning attitude. Being successful in analytic courses is not a guarantee for succeeding in experiential courses. Conversely, students which are not so-successful in analytic courses may have an outstanding performance. So, the research question was to determine if the grades of the individual students in different kind of courses (theoretical, practical, mandatory, elective, different disciplines, PBL, PDP) would correlate in a different way among them. We took as primary variable the grade of 1st year basic courses (all of them with strong analytical contents and methodology).

In Spain, as well as in other European countries, the students obtain a University access mark by averaging the grades of the two last High School years and the result of a discipline-oriented exam, which is performed nationwide. This access mark is used to rank and select the students that intend to enroll a given bachelor in a given institution. In a previous study, already published (Bragós, 2022), we analyzed the correlation between the University access mark to the engineering studies, a usual a-priori success estimator, with the grades obtained in project-based courses and in all non-project-based standard courses. The results displayed a lower correlation with the capstone course performance (R=0.3) than the one obtained with the average of the other courses (R=0.6). Not only the correlation with the access mark in the PDP capstone project courses is lower but the prediction interval is also different. While it is almost impossible that a student with a low access mark obtains an outstanding average mark in the bachelor and vice-versa, there are students with a low access mark which have an outstanding performance in the capstone project, which is very good for their self-confidence and self-efficacy, and this is probably a result of the fact that a different kind of skills are promoted in these courses.

As a result of this first study, we realized the need of determining if this correlation would be similar comparing the results of different categories of courses of our engineering program and the PBL and PDP courses, designed and implemented according to the CDIO Standards 4 and 5. This is, using internal indicators instead of the access mark and improving the granularity of the study. The academic achievement previous to the University studies is usually considered a good a priori estimator of academic success in higher education. Newman-Ford et al. (2009) relate it with the success in the first-year attainment and in the drop-out rate. Putwain et al. (2013) studied its effects in academic self-efficacy. The university access mark, however, can be biased by the kind of school in which the students had the secondary education. The grades of the 1st year course are, however, obtained in a homogeneous way. The aim of this communication is to present the results of this analysis. A similar study, performed in the UPC Architecture School was reported by García-Escudero et al. (2022), which also revealed low correlation between analytic skills and performance in project courses and identified clusters of homogeneous courses through correlation of grades as result.

METHODS

The previous study (Bragós, 2022) included the students of 10 academic years (2011-2021). Along these years, there were several slight changes in the curricula. In order of having a coherent set of courses to study the cross-correlations among them, we have limited the scope in the study we are reporting to 4 academic years, 2015-2016 to 2019-2020. We have included only the 762 students that have completed all the same courses (except the electives) including the bachelor thesis.

Assuming the limitations of the individual final grade as a valid metric to assess the performance of the student in a subject, we have chosen this performance index for this study because of its integrative character in the case of the project-based courses (PBL and PDP). According to the learning outcomes of the course, the project supervisors assign a team mark, which reflects the assessment of the process (50%) (Preliminary and Critical Design Review, team dynamics) and the final result (50%) (Solution Technical Performance, Business Idea, Final Report, Final Presentation and Video). The individual marks are obtained from this team mark after applying a triple modulation (30% max): The Supervisors' Assessment of the individual performance, the Team Leader assessment (batch of points) and the Peer Assessment using a 10 criteria rubric. Therefore, the final individual marks are quite integrative of several aspects. We have analyzed four consecutive cohorts that have completed a coherent set of subjects, n=762 students. We have classified the subjects (40 courses per student in average) in the categories aforementioned.

The Telecommunications Engineering Bachelor Program is distributed along four years (8 terms) as shown in Table 1, where all the subjects are depicted. To analyse the related behaviour between these subjects and the PBL and PDP ones, different classifications have been made, according to the contents and/or the kind of knowledge they contain. The parameter to be correlated is the individual average mark in each of the subject's group. Attending to this, three different classifications have been made. The first one, named Classification 1, groups the subjects which are considered Basic, containing all the first-year subjects, Mandatory, containing the disciplinary second- and third-year mandatory subjects, and Elective, including only Major Elective, containing part of the third- and fourth-year ones. The second classification, Classification 2, considers if the subject has scarce practical contents, and then it is considered as Theoretical or if it has medium to high practical contents, and then it is marked as Practical. And finally, Classification 3, groups the subjects in the ones that have high math and/or physics contents, naming them Science, and the subjects related to the different majors: in Electronics, Telematics/Networks, Telecommunication Systems and

Audiovisual Systems and Signal Processing. It is important to clarify that almost all courses included in these categories, except the PBL and PDP ones, have a high level of abstraction and include mathematical analysis methods which are assessed. The transversal elective courses which are non-disciplinary, have been excluded.

Figure 1 displays all this information as follows. Classification 1 is shown marking the subjects in black squares. Classification 2 is shown by marking P on the subjects that have been considered as highly Practical and finally Classification 3 uses the subject colour to indicate the essence of the subjects, whether they are pure scientific based (mathematics, physics in cyan on Figure 1) or they contain more specific disciplinary knowledge, namely related to electronics (green), telecommunications systems (violet), telematics/networks (pink) or Audiovisual Systems and Signal Processing (yellow). All the Elective block is coloured in different colours as it will depend on the chosen major and information about whether they are theoretical or practical is not depicted on the Figure for the sake of clarity. The subjects marked in Orange are the PBL and PDP ones, and there is always a final bachelor Thesis (TFG). In the Figure 1, transversal electives and practicum are also shown, although they have not been considered for this study.

Table 1: Telecommunications Engineering Bachelor Program depicting the different group of subjects considered in each classification. Namely: Classification 1 distinguish the subjects in black squares. Classification 2: marking with a P the subjects that have been considered as highly Practical. Classification 3: uses the subject colour to indicate the essence of the subjects: Cyan: scientific based (mathematics, physics); Green: Electronics; Violet: Telecommunication systems; Pink: Telematics/Networks; Yellow: Audiovisual Systems and Signal processing.

Term	Telecommunications Engineering Bachelor Program				
4B	Elective / Practicum	Elective / Practicum	**TFG (Bachelor Thesis)**		
4A	Elective / Practicum	Major Elective	Major Elective	**PDP**	
3B	Major Elective	Major Elective	Major Elective	Major Elective	Economy and Management (P)
3A	Microprocessor Systems Design (P)	Radiation and Propagation	Data Transmission	Audiovisual and communication signal processing	**PBL**
2B	Electronic Systems (P)	Electromagnetic waves	Telematic applications and Services	Communication Introduction	Audiovisual Processing Introduction
2A	Digital Design (P)	Electromagnetism	Systems and Signals	Statistics and Probability	**PBL**
1B	Linear Circuits and Systems (P)	Introduction to Telematic Networks	Object Oriented Programming (P)	Telecommunication s Mathematics	Vectorial Calculus
1A	Electronics Fundamentals (P)	Physics Fundamentals	Programming Fundamentals (P)	Linear Algebra	Calculus

For each combination, the Pearson's R correlation coefficient was obtained and the linear regression between each indicator and the access mark was represented, including the +/- 95% prediction interval around the regression line. The analysis tools we used were Matlab

(The MathWorks, Inc., Natick, Massachusetts, United States.) and SigmaPlot 14.5 (Systat Software, UK).

RESULTS

Correlation between the marks obtained in the different groups of subjects with the marks obtained in PBL, PDP and the TFG has been made for the three classifications. Figure 1 shows the results of the correlation matrices for the three classifications.

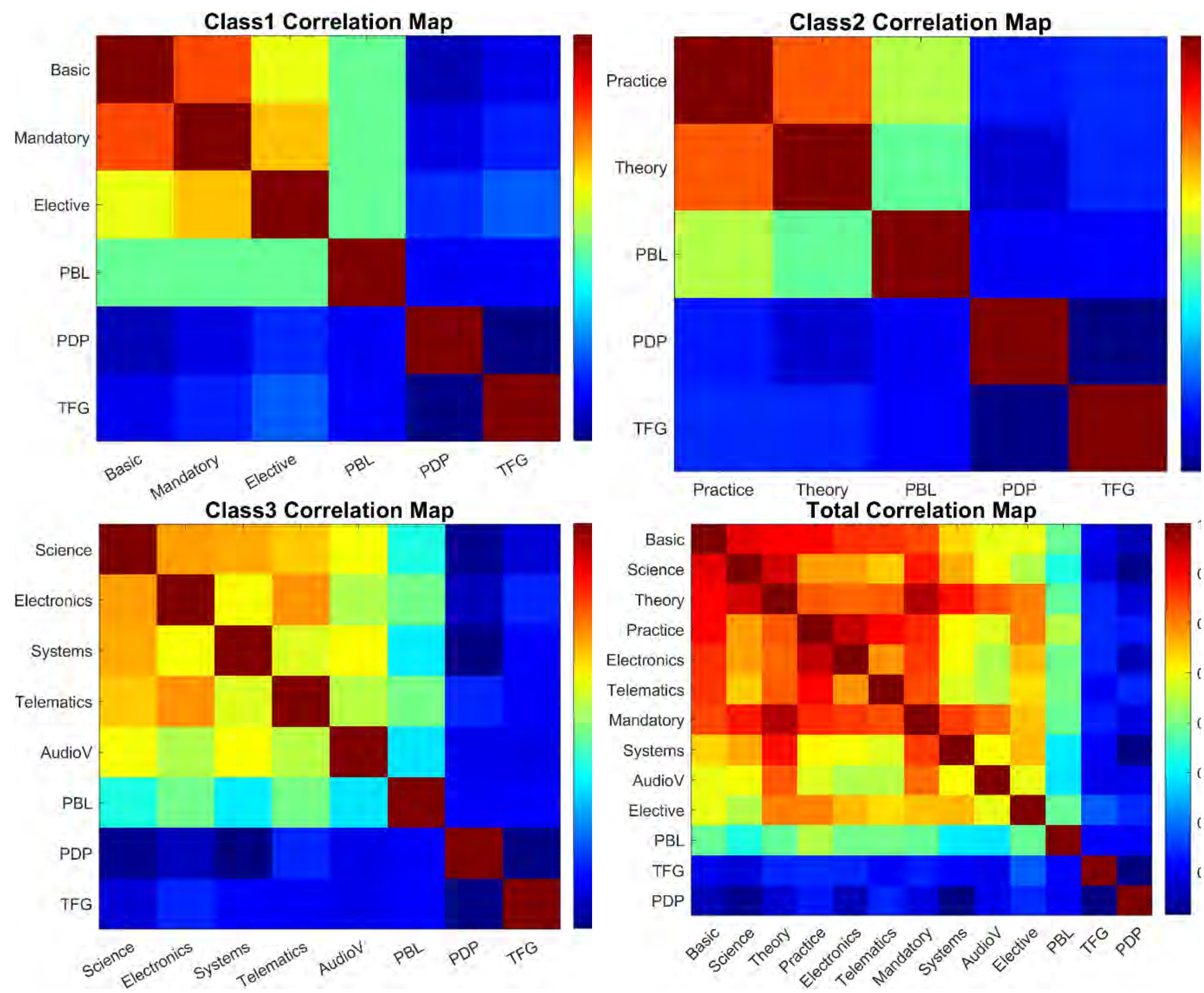

Figure 1. Correlation maps showing the marks correlation coefficients of the groups of subjects with PBL, PDP and TFG, in three classifications: 1) Classification 1, up-left: Basic, Mandatory and Elective subjects; 2) Classification 2, up-right: Practical and Theoretical subjects; 3) Classification 3, bottom-left: Science, Electronics, Systems, Telematics/Networks, Audiovisual Systems and 4) bottom-right: All the groups together. Note that there is symmetry in each of the matrices.

The first classification shows that the Basic block of subjects is in good agreement with the Mandatory block and it is also highly correlated with the Elective one. In general, there is a modest correlation of any of the Classification 2 groups with PBL subjects and it is almost null with PDP and TFG.

Classification 2 shows that practical and theoretical subject groups are highly correlated among them, slightly correlated with PBL subjects and, as in the previous case, there is a very low correlation with PDP and TFG.

Classification 3 shows that there are some subject categories that are more correlated in terms of the obtained marks, with the scientific ones, like Electronics, whereas others, like Audiovisual Systems and Signal Processing are less related. Electronics and Telematics/Networks slightly correlate with PBL subjects and, as in the previous analysis, none of the groups correlate with PDP nor TFG.

Finally, a total comparison of the different classification is shown. Table 2 shows the same information than Figure 1.4), in order to give all the exact data and facilitate a “one-glance” summary. There is an important remark in these results, as some of the subject groups include shared subjects, and this will alter the results, this is the case of Basic, Science and Theoretical subjects, as an example. The correlation matrix shows high correlation between the marks obtained in Science, Basic, Theory, Practice, Electronics, Telematics and Mandatory subjects, whereas there is a medium to high correlation between the marks obtained in Telecom Systems, Audiovisuals and Electives. As in the previous results, there is a medium correlation of most of the subject groups with PBL subjects, while the correlation with PDP and TFG remains very low.

Table 2. Correlation R values between all the different classifications average marks.

R value	Basic	Science	Theory	Practise	Electronics	Telematics	Mandatory	Systems	AudioV	Elective	PBL	TFG	PDP
Basic	1,00	0,92	0,90	0,90	0,86	0,86	0,84	0,74	0,69	0,69	0,59	0,30	0,26
Science	0,92	1,00	0,93	0,78	0,78	0,74	0,88	0,77	0,70	0,65	0,53	0,28	0,23
Theory	0,90	0,93	1,00	0,83	0,82	0,83	0,96	0,89	0,83	0,80	0,58	0,34	0,28
Practise	0,90	0,78	0,83	1,00	0,95	0,90	0,87	0,71	0,68	0,80	0,65	0,34	0,33
Electronics	0,86	0,78	0,82	0,95	1,00	0,79	0,86	0,70	0,64	0,76	0,60	0,34	0,26
Telematics	0,86	0,74	0,83	0,90	0,79	1,00	0,84	0,68	0,65	0,73	0,60	0,30	0,34
Mandatory	0,84	0,88	0,96	0,87	0,86	0,84	1,00	0,85	0,82	0,75	0,59	0,33	0,29
Systems	0,74	0,77	0,89	0,71	0,70	0,68	0,85	1,00	0,70	0,76	0,50	0,31	0,22
AudioV	0,69	0,70	0,83	0,68	0,64	0,65	0,82	0,70	1,00	0,69	0,49	0,30	0,30
Elective	0,69	0,65	0,80	0,80	0,76	0,73	0,75	0,76	0,69	1,00	0,59	0,38	0,34
PBL	0,59	0,53	0,58	0,65	0,60	0,60	0,59	0,50	0,49	0,59	1,00	0,31	0,30
TFG	0,30	0,28	0,34	0,34	0,34	0,30	0,33	0,31	0,30	0,38	0,31	1,00	0,21
PDP	0,26	0,23	0,28	0,33	0,26	0,34	0,29	0,22	0,30	0,34	0,30	0,21	1,00

To have a more visual and quantitative information, some of the correlation coefficients have been displayed in bar plots. Figure 2 shows these results.

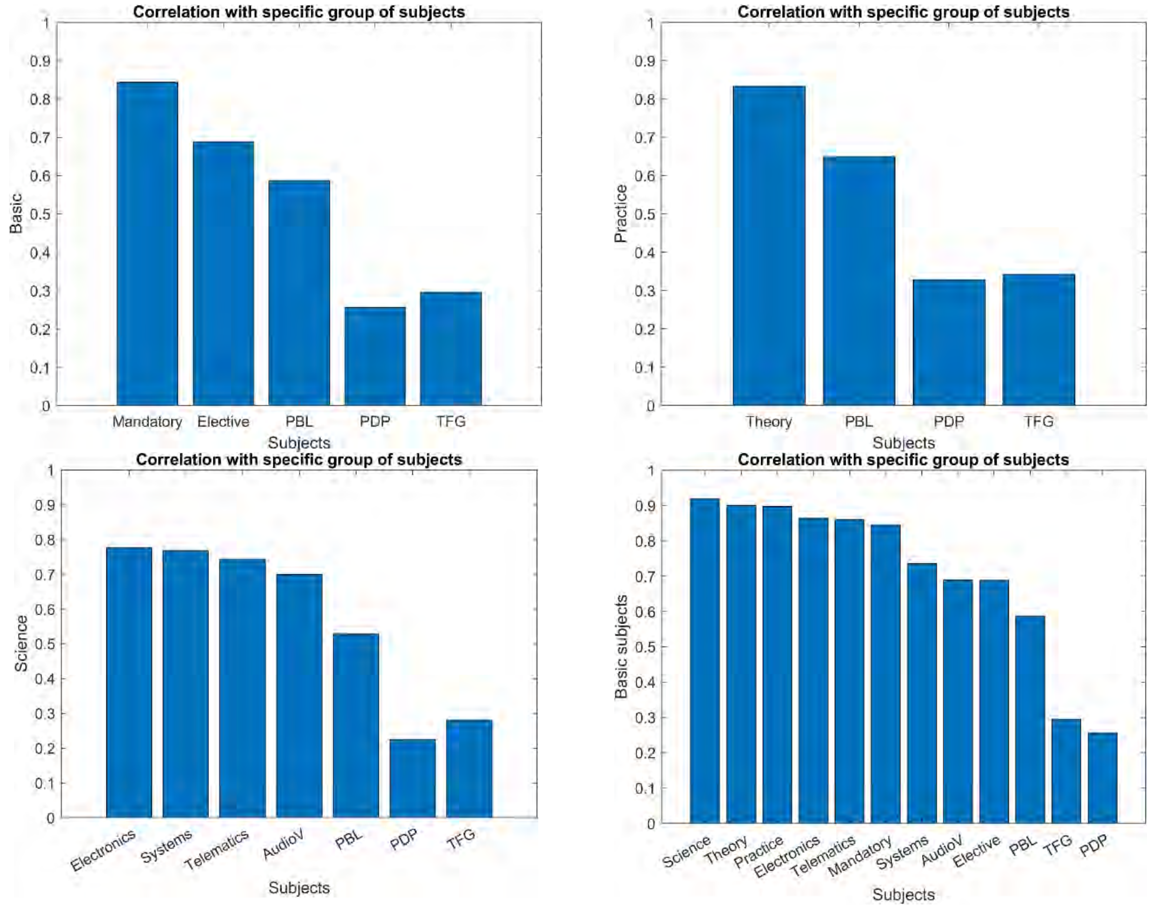

Figure 2. Correlation coefficients of the marks: 1) Basic subjects correlated with Classification 1, up-left; 2) Practical subjects correlated with Classification 2, up-right; 3) Science subjects correlated with Classification 3, bottom-left; and 4) Basic subjects correlated with all the subject groups.

As it can be observed in Figure 2, the marks obtained in the Basic group highly correlate (R=0.84) with the marks obtained in the Disciplinary Mandatory group, the correlation with the Elective group is R=0.69 and it is R=0.59 with PBL subjects. The correlation with PDP and TFG is R=0.26 and 0.30, respectively. The practical subjects' marks are highly correlated with the theoretical ones (R=0.83), while their correlation with PBL subject marks is R=0.65, whereas the correlation with PDP and TFG marks is R=0.33 and R=0.34, respectively. Finally, just comparing the Science related subject marks with the other contents, the higher correlation is found with the Electronic subject marks (R=0.78), followed by the Telecommunication Systems subject marks (0.77), Telematics/Networks (R=0.74) and Signal Processing and Audiovisual Systems (R=0.70). The correlation with PBL, PDP and TFG subject marks is R=0.53, R=0.23 and R=0.28, respectively. The last part of Figure 2, at the bottom-right, shows the correlation of the Basic subject marks with all the other categories. The bar plot has been ordered form higher correlation values (R=0.92), to the lower correlation value (0.26), obtained for the PDP subject.

In order to better interpret these correlations, the following figures display the linear regression between the individual basic courses' marks (x axis) and the other groups individual marks (y axis). The thick red lines display the linear regression line and the 95% confidence interval of the regression while the dashed red lines indicate the +/- 95% prediction interval of the indicator if the regression is used for this purpose. All graphs have the same axes scale in order of making easier their comparison.

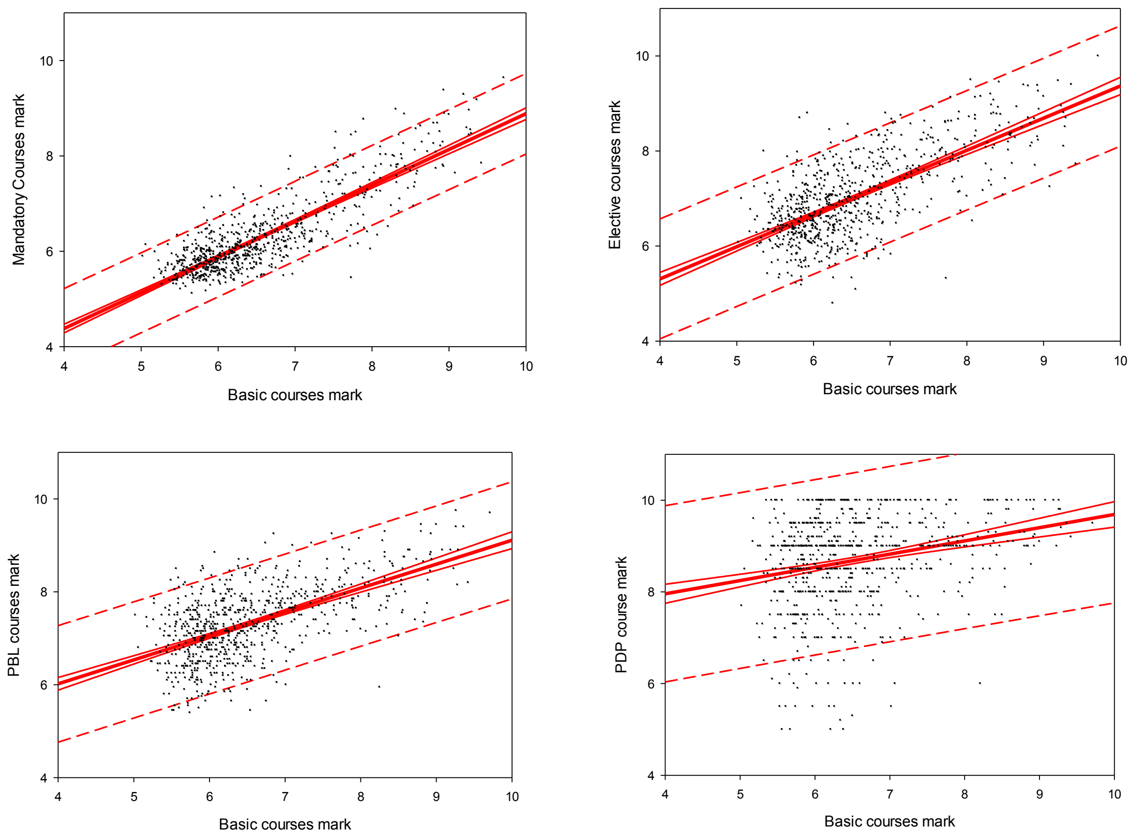

Figure 3. Correlation Basic courses mark – Disciplinary Mandatory courses mark (top, left); Correlation Basic courses mark – Disciplinary Elective courses mark (top-right); Correlation Basic courses mark – PBL courses mark (down-left) and Correlation Basic courses mark – PDP course mark (down, right).

As we can see, in addition of the correlation value, we can observe that the probability that a given student with low average marks in the basic courses reaches good marks in the disciplinary mandatory or elective courses is almost null, and vice-versa. It is a bit higher in the PBL courses. In the PDP capstone course, however, there are a lot of students with low performance in the basic (more analytical) courses which are able of obtaining a good and even outstanding mark.

DISCUSSION

As explained before, the Telecommunications Engineering Bachelor program is mostly oriented to acquire deep theoretical knowledge by means of master classes with a high mathematics and physics contents. Most of the subjects of the program, even the Elective and Practical ones are based on this philosophy. PBL subjects, although partially guided, are project based and mostly intended to acquire generic skills, but the challenges are defined by the supervisors in order to also acquire some specific disciplinary knowledge. The students can interpret them as a practical course but not so different to other courses with laboratory activities. They are intended to be training activities to face the PDP course in the fourth year.

This PDP capstone course includes a complete product or service development and demands very different skills than the ones asked in the rest of subjects. This subject proposes different projects, defined by the industry or other external institutions. The students make groups of 7 to 12 people to develop the chosen project and they have freedom to choose the kind of project. There is scarce guidance in terms of identifying the real and feasible goals of the project, the best way to solve them, how to face the challenge and identify risks, and develop a contingency plan. They also distribute the time, and coordinate the tasks between the teammates. Some of these skills have been worked in practical and PBL subjects. But this PDP subject is the first one that faces all these challenges. At the same time, it is the first time that the students really choose the contents of the challenge among 8-10 alternatives, and this is highly motivational.

The results lead to some interesting conclusions. It is remarkable the high degree of correlation of the theoretical and practical subjects. As described before, the program of the bachelor is highly demanding and has a very theoretic orientation. So, even the so-called practical subjects, are in fact a mixture of theory and practice, and even the practical part, includes deep calculations and many times written exams to score for this part. It is also interesting that the group of subjects that show a best agreement with the science subjects are the Electronics ones. It has been observed a highly vocational profile in these students, who usually look more into the practical approach of the problems. This seems somehow to correlate with their scores in mathematics and physics subjects.

As for the core of this study, the results of correlating the average marks obtained in any of the master classes with PBL and PDP are clear. All the subjects group marks mildly correlate with PBL subjects, but none of them correlates with PDP in a significant way. The practical, Electronics and Telecommunications and programming subjects' marks correlate more than the others with PBL, but again, no correlation with PDP is found in any analyzed case. Actually, PDP does not correlate with any group of subjects, neither with PBL nor the TFG. At this point it is also remarkable that none of the groups correlate with TFG, not even PBL and less of all of them, PDP subject. This is an unexpected result of this work, and could have an easy explanation, as the TFG is a special part of the program, with a very different score and methodological working system. TFG is performed individually and, usually, in an external company or in a research lab. It usually gets a high mark, once the objectives have been reached and the results are correctly reported. Reaching this point, the discussion should be oriented to finding a possible explanation for the obtained results. Let us move then to the why. The higher correlation of PBL with the rest of subjects would come from the methodological similarities that they share. The goals, steps and deadlines are clear and partially guided. So, as a first approach to active learning, the people with not sufficient skills regarding project development, can still find a way through the subject. On the other hand, PDP asks for the first time for very specific skills, not asked till now. And people that was forcedly embedded inside the master class methodology is for the first time able to develop other fruitful qualities. The group-working oriented project gives freedom to locate every person in the group in their most efficient position, and they greatly enjoy this new paradigm. This is something that is completely different in the TFG development. Although the student usually choses the contents of the work, that motivates and is very well fit for them, the work is mostly individual, the methodology is set by the actual supervisor and the results of the evaluation process are decided for and external committee, which evaluates the whole of the TFG.

Besides, the analysis of the linear regression between the individual basic courses' marks with the other group's individual marks, Mandatory, Elective, PBL and PDP, clearly show that there is a relevant set of students with not good performance in the basic subjects which get really high scores in PBL and even more in PDP. Something similar was observed in our previous work (Bragós, 2022), but in this later case, the primary variable was the University access mark to the engineering studies. In this previous study, however, there was also a (more reduced) set of students with high University access mark who showed low performance in project-based-subjects. In this work, we show that students obtaining low marks in basic subjects can obtain very high scores in PBL and even more in PDP subjects but brilliant students in basic analytical subjects also obtain high scores in PBL and PDP subjects, which is also an excellent result. In our opinion, the reason for the difference with the previous study is the possible higher bias in the access mark than in the internal basic courses grades as performance index. It is also clear that these performance indexes do not cover all the needed skills but only the ability to succeed in courses with analytical contents and methods.

We think that these results are very encouraging, as they confirm that PDP subjects help to exploit a wide range of skills and capabilities, and students that are not excellent in the analytical master class subjects, can brightly succeed in project-based subjects increasing their self-confidence and future self-developing. As an academic institution, and as a society, it is important to find the best way for our students to learn and reach their maximum development.

This works wants to depict the evidence that PDP subjects clearly work on the development of different skills than the ones obtained in regular, master class-oriented subjects. We would like to work more on the explanation of these results, as many questions arise from these results. Is it possible to conclude that this learning process is more important, or, better to say, complementary, to the one based only on master class development? Many well-founded research points in this direction, even concluding that this is the best procedure for the most talented students (Wieman, 2019), (Price, 2022). This is the other important question, is it the best learning procedure for all students or only for some of them, and in this case, which ones? Not all student profiles are the same, nor the capabilities or the motivations, and, although it is important that all the skills are included in the learning process, tuning which ones have to be introduced, and at which part of the process, may be of paramount importance.

We acknowledge the limitation of using only the grades as performance indexes and have asked for an internally funded project to measure the skills which are intended to be promoted in the PBL and PDP courses in a more comprehensive way. There is also a PhD thesis ongoing which will perform measurements in this direction. As a result of the feedback received from the students and of the first aforementioned study, confirmed by this one, a new elective itinerary was defined last year in two of our masters which allows the students to choose more electives around innovation and entrepreneurship instead of technological or scientific courses. These courses are mostly challenge-based. A relevant insight of the feedback was that there were students who said that they discovered their vocation about technology-based innovation in the PDP course.

CONCLUSIONS

In this work a detailed analysis comparing the student's performance in the regular, mostly analytical subjects and project-based subjects (PBL and PDP) is shown. The analysis has been made in the Telecommunications Engineering Bachelor Program, with a sample of 762 students corresponding to 4 cohorts which have followed the same curriculum. Correlation calculations have been made between the average marks obtained in basic subjects, with mainly analytical contents, and mandatory and elective subjects, also with mainly analytical contents. Other studies have been made correlating PBL and PDP performance with theoretical and practical subjects and also among the different disciplines. All studies show that whereas basic subjects highly correlate with the mandatory and elective ones (R= 0.84 and 0.69, respectively), the correlation with PBL decreases (R=0.59) and very low correlation is found between basic and PDP subjects (R=0.26). Similar results are found comparing different disciplines, where most of the disciplines correlate with the basic or science contents subjects (R ranging from 0.78 to 0.70, depending on the discipline), the correlation with the PDP subject is minimum in all of them. Regression analysis between the individual basic courses' marks with the other group's individual marks also supports that students with low marks in basic analytical courses may obtain high scores in PDP subjects, but not in the advanced analytical courses, whereas students with high marks in the analytical courses would also succeed in project-based subjects. We think that these results reassure the need of including that kind of courses as they open a way for all the students to fully develop their skills, increasing their self-confidence thus increasing their perception of a potentially good performance in their future career.

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ONLINE AND BLENDED LABS FOR PRACTICAL MECHANICAL ENGINEERING

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ABSTRACT

Lab training is a key element in most engineering education programs in preparation for engineering profession tasks. Universities worldwide are exploring new possibilities and different forms to arrange online and blended labs as an alternative to pure campus training. This study compares online and blended lab setups in four cases of engineering education at European technical universities. The results show that online and blended labs can achieve similar learning outcomes, with blended labs being particularly effective in combining online learning with hands-on elements. Students reported high levels of satisfaction and teachers noted the benefits of online learning environments, but common challenges included ensuring student engagement, increased self-regulation requirements, and the high effort needed to design online or blended environments. The study provides course design guidelines and discusses implications for future research and implementation in universities worldwide.

KEYWORDS

Online learning, Online labs, Hybrid labs, Remote labs, Blended learning, Hybrid teaching, Standards 5, 6, 8

INTRODUCTION

Lab training is an essential component of most engineering education programs, providing students with the opportunity to engage in experiential and inquiry-based learning activities such as experimentation and testing (Hofstein & Lunetta, 2004). These hands-on experiences allow students to apply and reinforce theoretical knowledge, work with technical equipment and designs, practice teamwork, and analyze and reflect upon experimental data through report writing. However, traditional lab training can be costly, may have limited accessibility, and pose potential safety risks. In response to the COVID-19 crisis and the increasing use of educational technology in education, universities around the world are exploring online and blended lab options as alternatives to in-person training (Graham, 2022). While there is a growing body of literature and case studies on online and blended labs, little effort has been made to compare the benefits, drawbacks, and effects on student learning between different types of lab experiences. This is particularly true for labs with heavy equipment, where often, the only solution for online learning has been videos with no interaction between lecturer and students.

In this paper, we aim to address this gap by conducting a comparative analysis of four learning designs that incorporate online or hybrid labs and were developed at different European technical universities. These learning designs include two cases of using and programming an industrial robot, one case of introducing manual welding, and one case of designing, programming, and testing logic control circuits.

STATE-OF-THE ART

Online labs have been explored as a potential alternative to in-person labs, and while the latter offer the benefits of realistic data, interaction with real equipment, and the ability to collaborate and interact with other students and teachers, they also come with high costs, time and place constraints, and scheduling and supervision needs (Nedic et al., 2003). In the literature, two main types of online labs are commonly distinguished: virtual and remote (Chen et al., 2010). Virtual labs refer to simulated lab environments using software such as Matlab/Simulink, LabView, or Java Applets. Remote labs are lab experiments with real instruments and/or components that are controlled remotely through the internet, either directly or through instructions to on-site staff. Both types of online labs have been studied in terms of their advantages and disadvantages as well as their impact on student learning. Research has also provided case studies examining the design and evaluation of various virtual and remote lab environments with varying levels of technical complexity (e.g., Wang et al., 2015; de Jong et al., 2014; Potkonjak et al., 2016).

There have been numerous studies that have identified potential benefits and risks of virtual and remote labs compared to traditional labs (Potkonjak et al., 2016; Chen et al., 2010; Post et al., 2019; Nedic et al., 2003; Lynch & Ghergulescu, 2017; de Jong et al., 2014). Some of the most commonly cited benefits of integrating virtual and remote labs in higher education include cost reduction and simplified maintenance of lab facilities, as well as the ability to provide students with a safe learning environment that can be accessed from anywhere. Both forms of online labs offer cost-saving advantages, as virtual labs are easier to set up and maintain and involve lower equipment costs, while remote labs can be used more efficiently through shorter time slots and non-stop scheduling. Additionally, online labs offer greater flexibility in terms of access and set-up, as they can be available 24/7 and allow geographically distributed learners the opportunity to collaborate and cooperate with each other and the instructor remotely.

Remote labs also offer the benefit of allowing students to interact with real equipment, while virtual labs enable a wide range of experiments with different components and system configurations that can easily be repeated and allow for greater transparency in the inner workings of lab devices without the risk of damage or harm. However, there are also risks. Virtual labs do have the disadvantage of not actually existing, which can result in a lack of real-life feel and a sense of seriousness for students who may view the virtual lab more as a game, making it difficult to effectively teach about important health and safety issues. Additionally, even in remote labs, students are only present virtually in the lab. There are also risks of oversimplification and lack of natural variation in virtual labs, and adapting virtual labs to a specific class context requires a high level of understanding of the underlying software. Professional development for teachers to create well-designed inquiry environments in online labs can also be a significant challenge.

According to Brinson (2015), who conducted a review of 56 studies, learning outcomes from virtual or remote labs were equal to or better than those from traditional labs. For instance, Wang et al. (2015) found that students using a virtual physics lab had greater depth of practice in process skills, comprehensive skills, and reflection skills of scientific inquiry compared to those in traditional lab environments. A review by Post et al. (2019) also found positive results in terms of gain of conceptual knowledge, student engagement, and student satisfaction with regard to remote labs. However, they also noted that the review of learning outcomes was superficial, as most articles did not focus on that aspect and further research is needed. Potkonjak et al. (2016) also highlighted the limited generalizability of most online labs, which are typically adapted to a specific educational context. Some authors have emphasized the need to improve learning in online labs through more careful design and coordination of group and individual activities (Corter et al., 2011). Others have argued that online labs, while valuable in education, cannot completely replace traditional lab environments and their usage should be balanced with the simplicity and physical experience of the student actually being in the lab (e.g., Scheckler, 2003; Sicker et al., 2005).

A suggested way to address some of the drawbacks of online labs is to combine remote labs and virtual labs into hybrid labs (Rodriguez-Gil et al., 2017; Henke et al., 2013; Lei et al., 2018). These labs offer the scalability and cost-effectiveness of virtual simulations, as well as the authenticity of remote labs. While still relatively new, initial evidence suggests that this format is engaging for students and has educational potential (Rodriguez-Gil et al., 2017). Hybrid labs have also been used to refer to the combination of online and real lab sessions. However, there has been little research on this format so far. This type of learning design aims to provide students with the flexibility of remote or virtual labs, as well as real-world hands-on experiences (Zhu, 2010). A recent study in chemistry (Enneking et al., 2019) found that, compared to traditional labs, this format resulted in similar cognitive and psychomotor development for students, but the students were less able to see real-world connections and spent less time reflecting on underlying concepts.

The results of studies on the effectiveness of virtual and remote labs in replacing physical labs are thus mixed, highlighting the need for careful design and adaptation to the educational context. While there is some evidence to support the use of virtual and remote labs, particularly in terms of cost efficiency and flexibility, further research is needed to fully understand the potential of hybrid solutions, which combine the benefits of online and traditional lab environments.

METHOD

This comparative case study (Goodrick, 2014) aims to explore the experiences, challenges and best practices of conducting online labs in engineering education. Four cases of blended and online labs were included in this study based on their participation in the Prameco project. Data was collected through teacher reflections on open survey questions.

The participants in this study were four teachers who reported on their experience conducting online labs in higher education. An open-ended survey was designed to elicit reflections from the participants on their experiences and challenges of conducting online labs. The survey consisted of eight open-ended questions along the dimensions: lab set-up, learner performance, activity and satisfaction, teacher workload, experiences benefits and drawbacks of the lab as well as design recommendations. While we asked the instructors to describe their experiences and challenges in their own words, we invited the integration of further data sources like student evaluations or experiences of co-teachers into the answers. While this approach has clear limitations in terms of the rigor of the data collection methods applied, it enables the integration of different data sources from the four cases that otherwise might be incomparable. The survey was distributed to the participants via email in November 2022 and answers received in December 2022.

The responses to the open-ended survey questions were analyzed and summarized under the themes (1) set-up, (2) student experience, (3) teacher experience and (4) design recommendations. After the data from each case had been analyzed, the cases were compared to identify similarities and differences in the experiences and challenges of conducting blended and online labs. This comparison allowed for a deeper understanding of the factors that influence the success or challenges of online labs.

RESULTS

Set-up and context

In this section, we briefly present the four different lab set-ups as they were implemented in the different universities.

Case 1 Remote live lab: Using and programming an industrial robot (Turku University of Applied Sciences)

The online lab session titled "Introduction to industrial and collaborative robots" was held for students in their second and third years. The session was conducted via Teams due to COVID-19 restrictions, with groups of around 20 students participating. The session lasted for two hours and included interactive elements such as online polls and quizzes. Students were able to see the robot, the robot's user interface and the teacher through video streams and communicate with the teacher through voice and chat. The demonstration was divided into three parts: a warm-up poll to assess students' prior knowledge and ensure they could connect to the online services, a demonstration of various robot capabilities, and a final discussion and poll to assess understanding. The demonstration covered topics such as moving the robot, using the gripper, modifying motion instructions, using the force sensor, and relative motion commands. There were brief discussions and polls after each topic to encourage student participation.

Case 2 Hybrid virtual lab: Using and programming an industrial robot (Tallinn University of Technology)

The practical lab work "Pick and Place Boxes" is part of the course "Industrial Robotics and Advanced Manufacturing - project" for last year's master's program in Industrial Engineering and Management. In previous years, the lab work was conducted in a computer classroom with around 20-30 students participating. The teacher used a projector and whiteboard to explain the task and demonstrate how to use the ABB RobotStudio software to move the robot, teach positions, and write a robot program for picking and placing a box. Students were then tasked with completing the program to have the robot pick and place multiple boxes onto a plate. At the end of the lab work, students demonstrated their completed programs on their own computers. This lab work was one part of several tasks that students had to complete in order to build a virtual robotic production line for a company or factory by the end of the course. In 2022, the lab work was held in a hybrid format, with 4 out of 30 master's students participating online. The teacher used a PowerPoint presentation and the ABB RobotStudio software, an extra screen to monitor the chat as well as a speakerphone to transmit and record their voice. The lab work was transmitted and recorded using BigBlueButton. Students participating online needed to install the ABB RobotStudio on their computers and use two screens, one for monitoring the teacher's work and the other for working with the software.

Case 3 Hybrid lab: Introduction to manual welding (HAW Hamburg)

The lab event related to the "Joining Technologies" lecture at HAW-Hamburg is part of the fourth semester and typically has around 45-70 students. Previously, students were divided into groups of 10-15 for each lab event, which included common welding and joining processes such as such as electrode and gas metal arc welding. The new lab setup includes three stages: *Lab on demand* (short online videos teaching the basics of various processes in preparation for the live labs), *digital live labs* (interactive online demonstrations of the welding process for all students, with several cameras at different angles and student input on different parameters), and *practice welding* (small groups of 10-15 students on site to apply their knowledge). Each stage is completed by a small test students have to pass to continue. By digitizing the lab event, staff can teach all students in the course at once and students can prepare with the Lab on Demand content at their own pace. The labs also expand upon the previous offering of just manual electrode welding to include gas metal arc welding as well.

Case 4 Remote or hybrid lab: Logic control (Chalmers University of Technology)

The course "Logic Control" is given to approximately 100 first-year students and focuses on programming a Programmable Logic Controller (PLC) and a microcontroller, as well as signal conversion through electronic components to enable communication between the two systems. The course includes a few lectures at the beginning, but the main learning activity is a group project task. In a traditional on-campus format, students work on the project in the lab with access to physical components and the ability to test their results continuously. The course has been adapted to one purely online format and one hybrid format. In the online format of the course, students prepare solutions to the project task using simulators at home and are guided by the teacher in online consultation sessions. They must also submit a progress report each week. Twice during the course, students can test their solution with physical hardware during online sessions of 30-45 minutes. During these sessions, the teacher demonstrates the equipment and how the students' work functions. The students must answer questions about their preparations, describe the function of different components, and guide the teacher on how to connect vital parts of the electronics. The function test is used as part of the assessment of the students' knowledge. In the hybrid format, students prepare much of their work at home using simulators and online consultation sessions. They then test their solutions themselves in the lab on five occasions during the course and show them to the teacher. The students can choose to come online to two of the testing occasions. The progress reports are not used in the hybrid format due to the more continuous testing opportunities.

Student experience

In this section, we summarize the teachers' reflections regarding intended and achieved learning outcomes, student activity and engagement during the labs as well as their overall satisfaction with the set-up in the four different cases.

Case 1 Remote live lab: Using and programming an industrial robot (Turku University of Applied Sciences)

The learning objectives of the remote live lab were the same as those of traditional lab exercises - to provide students with an opportunity to learn the basics of collaborative robot operation and programming. The session allowed students to learn through equipment demonstration and lecture, but the learning outcome was potentially not as effective as traditional hands-on lab exercises. However, the perceived learning outcome was good, as most students reported understanding the topics well according to a poll taken after the session. On a scale from 1 to 5, with one representing "I didn't understand" and five representing "I understood well," each of the five topics scored over 4.2, with an average score of 4.3. Unfortunately, there was no report assignment or similar measure to verify the learning outcome for this course implementation. The teacher felt that the students were actively engaged and learning during the session, but this is difficult to confirm. To encourage student participation and engagement in the demonstration and lecture, they were designed to be interactive with discussions and polls. While students were responsive to direct questions, there was not much spontaneous discussion outside of the transition between topics and the closing part of the session. This may be due to the inherent delays in video meeting apps making communication difficult or frustrating. Collaboration assignments between students were not included in this session, but they were identified as an important and necessary aspect for future implementations. The overall response to the two implementations was positive, with no negative feedback received. However, it is difficult to accurately estimate student satisfaction, as this was not measured through a specific survey. Some students may have been disappointed that they were unable to practice with the robot on their own due to COVID-19 restrictions, while others with long commute times may have appreciated the convenience of not having to travel to school.

Case 2 Hybrid virtual lab: Using and programming an industrial robot (Tallinn University of Technology)

The intended learning outcomes of the lab work were for students to understand how a pick-and-place task is carried out by an industrial robot and to be able to teach robot positions in ABB RobotStudio, write a robot program, and simulate its work on a computer. The students also learned that some positions can be calculated and/or shifted in the robot workspace using corresponding functions. All students who participated in the lab work on campus successfully demonstrated their working robot solutions and programs at the end of the class. Of the 4 online students, only one asked for help multiple times and only 2 out of the 4 showed their end result through the virtual classroom software. The other two students completed the lab work several weeks later at the university, stating that during the online session, they were unable to observe the lab activities and use the software at the same time on their computers, despite that the teacher had asked for student input throughout the lab work to check for understanding and offer assistance. The student engagement during the lab work was different between online and on-campus students. In this teacher's experience, Estonian students are generally quiet and do not ask many questions, so the teacher made an effort to go around the computer class and offer assistance as needed. It was more difficult to interact and get responses from students when participating in the lab work online. To encourage student engagement, the teacher redesigned the slides to include questions that all students had to answer and asked for students' names at the beginning of the lab work. Overall, the students' perception of the new setup compared to traditional labs was positive. Two of the online students were happy to be able to participate in the lab work at all as they would have missed the session otherwise and the two other students appreciated a detailed video about the lab work for self-study purposes that the teacher recorded with the virtual classroom software. However, as a limitation the teacher observed that some students tended to postpone the lab work and extend the presentation of their results.

Case 3 Hybrid lab: Introduction to manual welding (HAW Hamburg)

In terms of learning outcomes, the main goals for this lab were for students to gain basic knowledge and skills in various welding technologies, including practical welding skills in electrode and gas metal arc welding. The students were able to achieve these learning outcomes and found the practical welding skills particularly valuable. In addition to learning theoretical knowledge about welding and cutting technologies and processes, the students were also able to observe these processes in action and discuss them with the lecturers during the online live lab events. This combination of being told the knowledge and seeing it demonstrated allowed for a more comprehensive understanding of the material. When it comes to student activity, the new setup has allowed for students to be more self-sufficient in their preparation for the final exam or stage tests, as they are able to collaborate and study together. However, the number of students actively participating in discussions has not seen a significant increase, even though opportunities for discussion and questioning have been expanded. Regarding student satisfaction, feedback on the new setup has been largely very positive. The students particularly appreciated the ability to have more practical welding time and the flexibility in terms of time and location offered by the blended format. The high-quality lab-on-demand videos were also seen as a helpful resource that is available at any time. Other benefits included more practical welding time as result of the course design and the ability to have more and deeper technical discussions due to the basic knowledge gained through the online pre-lab events. On the other hand, some students experienced minor technical issues (i.e., with their internet connection) and there was a lack of a "just in time" option for asking questions during the lab-on-demand portion. Additionally, it has proven difficult to build a "sense of community" in an online setting.

Case 4 Remote or hybrid lab: Logic control (Chalmers University of Technology)

Both the online and the hybrid versions of the course were intended to have the same learning outcomes as an on-campus version of the course, including the ability to work in a group to plan and execute a project, present logical solutions for Programmable Logic Controllers (PLCs) and microcontrollers (MCUs), manage program environments and design control programs for PLCs and MCUs, design components and circuit diagrams, and troubleshoot and verify function. However, it was difficult for students to reach the learning outcome of "realizing electrical circuits" in the online format, as they were not able to physically connect the components themselves. The level of troubleshooting was also lower in the online lab, as the teacher had prepared much of the circuit to minimize the risk for mistakes. In terms of grades, the number of students passing the course was similar between the remote, hybrid and on-campus formats, and highly dependent on their performance and participation in preceding courses. In terms of student activity, all formats saw students being engaged in their projects. However, students tended to finish projects somewhat later in the online format, and those who struggled with planning had a harder time getting started and needed additional encouragement, e.g. through the weekly progress reports. Overall, students were satisfied with the online version of the course and were glad to see their projects working in the online lab. However, they would have preferred to be in the lab to test their projects themselves. In the hybrid format, an element of preparations in the simulators was added in comparison to an on-campus format. That made it somewhat harder for the students, because they had to plan their time better and they sometimes had to troubleshoot their solutions twice, both in the simulator and in the lab.

Teacher experience

In this part, we summarize the teachers' perspectives on workload, benefits and drawbacks of their lab sessions based on their experiences.

Case 1 Remote live lab: Using and programming an industrial robot (Turku University of Applied Sciences)

The teacher assessed the concept of online live lab as a more efficient and effective way to teach and demonstrate the use of equipment, but also stated that it required additional effort compared to traditional lab work. Preparing and running the labs required more work compared to traditional labs (one to two workdays spread over several days), due to the additional steps involved in setting up and designing a demonstration, but also because of the lack of experience with the new setup. Running the remote live lab session was more stressful for the teacher, due to the required multitasking between programming the robot, running quizzes, controlling presentation, explaining the theory and practice of robot programming, managing the different video streams and angles, and monitoring chat, all at the same time. From the teacher's perspective, the benefits of online live labs include the ability to provide safe demonstrations to a large group of students, as well as the ability to record and access the content later, allowing students to review the material at their own pace. It also allows the teacher to interrupt the exercise more frequently to ask conceptual and reflection questions to improve the learning outcome. Additionally, for some students, a guided demonstration may be a better way to learn than self-directed learning. However, they acknowledged some drawbacks of using online labs, such as the lack of certain aspects of work or skills that cannot be learned remotely (e.g., using manual measurement tools). Additionally, not all subjects or applications are well-suited for online labs, as video recording certain equipment or display terminals may be difficult or impractical. Furthermore, online labs lack social interaction and can negatively impact motivation. Finally, the organization of online labs can be complex and requires additional work, which can be challenging for teachers who are unfamiliar with the equipment, software, and methods.

Case 2 Hybrid virtual lab: Using and programming an industrial robot (Tallinn University of Technology)

According to the teacher, the shift to remote laboratory work required some adjustments to the traditional workload and methods, but it also provided new opportunities for flexibility and accessibility for students. The teacher reported that the workload prior to the lab work has increased slightly, with an additional 1.5 hours required for doing the lab work, as well as a maximum of 20 minutes to watch late responders' lab work results. During the lab work, the teacher spent time testing broadcasting options and different equipment, preparing slide shows, and working with the lab work itself. Despite the increased workload, the teacher reported several benefits, a major one being the flexibility it provides to students. They can attend the lab work online from anywhere they are, allowing them to continue their education even when they cannot physically come to the university. Additionally, the teacher was able to record the lab work, which allows students to revisit things when they have forgotten something. There were also drawbacks and challenges. The teacher reported that it can be difficult to know if the recording was switched on or not, and if the correct part of the lab work is being streamed. Additionally, there is a risk of not hearing questions from online students when helping students in the class, and not being close enough to the microphone to be heard by online students. Furthermore, the teacher may forget to repeat questions asked in the class or on the online platform, leading to confusion for online students. However, with the proper preparation and resources, these challenges can be overcome to create a successful remote laboratory experience for students and teachers alike.

Case 3 Hybrid lab: Introduction to manual welding (HAW Hamburg)

The remote live laboratory setup was assessed to have both benefits and drawbacks. The teacher stressed the more efficient and effective way to teach and demonstrate the use of equipment, but also pointed toward the additional work and challenges regarding communication and feedback. Regarding the workload, the teacher reported that although the total number of lab appointments may have been reduced, more preparatory and follow-up work was required to ensure and improve the quality of the labs. This included the time spent scripting, filming, editing, and translating lab on-demand videos, as well as scripting and setting up online lab events. However, the teacher noted that the total workload per lab remains the same, with the majority of the additional work being shifted from preparing for individual lab events to preparing for digital and online alternatives. Numerous benefits of this new lab setup were mentioned. More students were able to attend lab events while maintaining a high level of quality, and there was a higher level of teaching quality for each individual student. Additionally, the further qualification of employees in the areas of digitization and teaching was promoted, and a new technical infrastructure (such as a computer supported, video and sound equipped welding station) was developed. The teacher also noted that staff can now focus more on teaching and less on repeating lab events multiple times. However, there were also drawbacks to this new setup. The teacher notes that communicating with reserved students can be more difficult due to the indirect communication that takes place online. Additionally, there is no direct feedback from students to the teacher through facial expressions or other nonverbal cues. The teacher also mentioned that moderation and teaching can be unfamiliar at first, as speaking to a blank screen rather than speaking directly to students in person can take some getting used to. There is also an element of indirect involvement in the lab through online tools. Altogether the teacher concluded that it is important to consider the pros and cons before implementing a similar setup in other educational settings.

Case 4 Remote or hybrid lab: Logic control (Chalmers University of Technology)

Overall, teachers reported that the hardware and software used in the online and hybrid formats functioned well and supported student learning, as well as student-to-student and student-teacher interaction. In the online format, the teacher workload increased in both the preparation and execution of lab sessions mostly due to the weekly reports and the tests that were conducted in groups of two. These additional tasks added an extra 8 hours of work to the teacher's workload. It was noted that the online consultation sessions were effective in that they allowed to meet and guide more students in an online session than in a lab session and thus were a way to reduce teacher workload. The hybrid format used some extra teacher time in the first setup of simulation tasks and assignments. However, once that is done, there are less lab sessions compared to an on-campus course and the teacher can meet more students in the online consultations. Thus, the hybrid format is more efficient in teacher workload. Despite the increased workload, there were several benefits to the pure online lab setup. One of the biggest advantages was that students could test their solutions and see them work in real equipment, rather than just in simulations. The experience where they saw their concept work provided a valuable learning opportunity for students and allowed them to better understand the concepts they were learning. There were also several drawbacks and challenges. One of the most significant challenges faced was helping students who were struggling to keep up as in particular quieter and less motivated students were found to be less likely to attend consultation sessions and complete their projects on time. Teachers reported that it was easier to motivate these students in a traditional lab setting. Additionally, function tests were an important aspect of the assessment in the course, and were also the only time students could use physical hardware. However, it was sometimes difficult to differentiate between helping and assessing students' knowledge in the remote testing sessions, which can lead to confusion. It was more difficult to keep track of individual student progress within a group in the online format. Thus, written tests and oral discussions are important in online and hybrid formats to determine individual grades.

DISCUSSION

This study was set out to present and compare four cases representing different forms of online and hybrid lab setups in engineering education using teacher reflections as empirical base. Only the first case represents a pure remote online lab, while the other three are different forms of hybrid setups. The comparative analysis of the four cases highlights different perspectives of the teachers about how their workload, necessary equipment, benefits and risk as well as student learning change when shifting from traditional labs to online or hybrid lab sessions. It should be noted that unlike previous research, the shift to a pure online format and a hybrid format has been prompted by the Covid-19 pandemic in most of the cases, which may significantly impact the delivery and student experiences in lab settings (Gamage et al., 2020). As such, the effects of the pandemic and changes in teaching staff have been included in our results, though we have attempted to remove these influences as much as possible for the sake of comparison. However, some residual effects may remain.

All teachers reported additional effort required in the preparation phase of the lab setups though those could partly be compensated through the opportunity to engage a larger group of students in activities compared to the traditional activities. As teachers become more experienced with the new lab setup, higher effectiveness in the preparation might also reduce workload in the future. During the session, teachers were also partly struggling with additional effort requirements in online and blended setups, such as the need to be multitasking, the additional effort of engaging online and campus students at the same time, as well as difficulties regarding student assessment.

In terms of learning outcomes, the cases show that online and blended laboratory setups can achieve similar results that in specific combinations of learning activities can even foster deeper learning as found in case 3. The comparison indicates better learning outcomes for blended set-ups, in which the benefits of online learning can be effectively combined with hands-on elements, while pure online lab exercises are potentially not as effective as indicated by the results from the remote live lab case 1 and the online participants from case 2. Nevertheless, students generally reported high levels of satisfaction, appreciating the flexibility and adaptability of the learning environments. In sum, those results confirm earlier studies suggesting that students achieved similar throughputs in online, hybrid and traditional learning environments (e.g., Brinson, 2015; Enneking et al., 2017) and expressed high levels of satisfaction in each format (Post et al., 2019; Corter et al. 2007). They also mirror global trends of leading engineering education institutions towards "*student-centered learning to large student cohorts through a blend of off-campus personalized online learning and on-campus hands-on experiential learning"* (Graham, 2018, 45, see also Graham, 2022)

Teachers reported increased possibilities for active learning and highlighted advantages of online learning environments over traditional laboratories such as teaching or demonstrating single equipment use to large student groups. On the other hand, they also consistently reported problems to engage with online students and a lack of spontaneous discussion. Thus, the importance for explicit interactive elements such as interactive elements such as online polls and quizzes was stressed. All teachers mentioned the increased accessibility and flexibility of online and blended labs as a main benefit together with the ability to provide safe demonstrations to a large group of students. However, the struggle to engage online students also is an indicator for higher demands on students' ability to regulate and organize their learning (Stöhr et al., 2020). Further, online labs also lack certain aspects of work or skills that cannot be learned remotely, reiterating the superiority of blended labs over pure online solutions (see also Olesen et al., 2021).

DESIGN GUIDELINES

Altogether, the analysis shows that the shift to remote and hybrid lab sessions require carefully considered adjustments in the learning design (see also e.g., Potkonjak et al, 2016), resulting in more work for the teachers. In all four cases, it is noted that the implementation of online and hybrid lab formats poses new challenges for teachers and students, and it is important to carefully design and execute these sessions to maximize their effectiveness. We conclude this paper with a number of design guidelines based on the teacher input from the four cases.

All four cases recommend using good hardware and investing in necessary equipment to ensure a smooth and effective online lab experience. Case 1 emphasizes the importance of making the lab work interactive by posing questions and encouraging students to propose solutions. Case 2 recommends designing the session to prioritize student participation and interaction. It suggests a variety of strategies to enhance participation, such as providing preliminary learning assignments, incorporating pauses for discussion, using quizzes, and assigning group tasks. It also recommends enlisting the assistance of a colleague to manage the presentation and chat and evaluating the possibility of equipping the lab space with audio visual (AV) equipment for remote learning sessions. Case 3 emphasizes the importance of familiarization with multimedia infrastructure, investment in hardware, development of streaming routines, and extensive preparation. Further, it highlights the importance of good hardware, moderation, and tailoring concepts and scripting to specific labs and lab topics. Case 4 recommends finding simulators that work for testing project results and meeting with students to assess individual performance. All four cases also recommend familiarization with multimedia infrastructure and the development of streaming routines as important for the success of the online lab. A list of the design recommendations can be found in Table 1.

Table 1. Guidelines: Implementing a online or blended lab set-up

Guidelines: Implementing a online or blended lab set-up
• Utilize best practices and proven equipment that align with your specific requirements and needs.
• Prioritize student participation and interaction, experimenting with ways to improve engagement.
• Assign preparatory learning tasks to prepare students for the session.
• Incorporate breaks between topics to allow for discussion, taking into account the potential delays of video meeting apps.
• Utilize online polls and quizzes, and group discussion or writing tasks during the session.
• Provide students with opportunities to direct the course of the demonstration and to test their own hypotheses.
• Ask questions directly to students
• Consider assigning a reporting assignment and instructing students to take notes during the session.
• Utilize an assistant to manage the presentation, video streams, and chat during the session to allow the teacher to focus on teaching.
• Invest in dedicated AV equipment for remote learning sessions such as multiple movable cameras, tripods, microphones, and pre-configured computers with software.
• Allow for ample teacher preparation time, including multiple test runs to familiarize yourself with the new setup.
• Be mindful that there is no one-size-fits-all solution and each lab event and topic may require its own unique setup.
• Meet with students to assess individual performance

CONCLUSIONS AND FUTURE WORK

In conclusion, this study aimed to present and compare four cases of different forms of online and hybrid lab setups in engineering education, using teacher reflections as the empirical base. The findings of the study indicate that while online and blended laboratory setups can achieve similar results to traditional labs, blended or hybrid setups seem to provide better learning outcomes. Additionally, it was found that the implementation of online and hybrid lab formats poses new challenges for teachers and students, and it is important to carefully design and execute these sessions to maximize their effectiveness. Considering these findings, the study provides a number of design guidelines based on the teacher input from the four cases, including the use of good hardware and investment in necessary equipment, the use of interactive elements such as online polls and quizzes, and the need for explicit strategies to engage online students. Further comparative research is needed to gain more insight into the area, such as meta studies and comparisons of multiple single-case studies to validate the transferability of our guidelines to other programs and lab contexts.

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VISUALIZING EXTRACURRICULAR STUDENT TEAMS LEARNING AT TU/e INNOVATION SPACE WITH CDIO SYLLABUS

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ABSTRACT

This paper's purpose is to present the findings of exploratory research performed at TU/e innovation Space to gain a better understanding of what students learn in extracurricular student teams. Having a better understanding of student learning can help us make such learning more visible, which has a positive impact on students' development of professional identity and employability. The scope of this study includes interviews with five *alumni* from student teams and an analysis of its outcomes. The results of the interviews' analysis showed that students recognized that they experienced learning gains because of their participation in student teams. However, the process of describing the learning gains in a detailed way is not easy for them, showing that their extracurricular efforts did not make these learning gains explicit. Students reported learning gains associated with personal and professional skills (CDIO syllabus section 2) and interpersonal skills, collaboration, teamwork, and communication (CDIO syllabus section 3). Peer interactions and learning by doing were the most relevant media that promoted those learning gains. Finally, we conclude that additional methods such as observations during teamwork can help understand the mechanisms that facilitate learning.

KEYWORDS

Extracurricular, Student Teams, Challenge-Based Learning, Learning gains. CDIO Standards: 1,2,3,4,5,7,8,11,12.

INTRODUCTION

TU/e innovation Space is the expertise center for Challenge-Based Learning and student entrepreneurship at Eindhoven University of Technology. The center is the umbrella for a student team program and facilitates around 700 students engaged in extracurricular student technology development teams. These students challenge themselves to tackle some of the world's complex challenges, together with over 500 external companies and organizations. Examples of these challenges are sustainable mobility (Team Polar, 2023), or accelerating the development of biosensors for health care (SensUs, 2023). The composition of the teams is diverse, their members are students from different programs and levels of education, their participation can be part-time (e.g., 10 hrs./week) or full time (e.g., ~40 hrs./week) depending on their time availability and willingness, teams shape their organization according to their needs, and the technological component of their projects ranges from technological divulgation to integration of existent technology in a novel way and development of new technology. Students in extracurricular student teams are characterized for their intrinsic motivation, students are not rewarded in any form, and their participation is voluntary. Finally, TU/e innovation Space provides coaching, technical support, physical space, and points them to financial and legal advice.

The Development Model (Seow & Pan, 2004) suggests that extra-curricular activities have a positive impact through an indirect effect on academic performance because of their non-academic and social benefits (Buckley & Lee, 2018). Empirical evidence indicates that extracurricular student team members experience learning gains in competences promoted in CDIO-based education including domain-specific knowledge and skills but also problem solving (Larson et al., 2006), interpersonal skills, communication, and working in teams (Clark et al., 2015). In addition, literature informs us that increased resilience (Thomson et al., 2013), social capital and social networks, discipline, and conformance to institutional norms and expectations (Stuart et al., 2011) are benefits of students' participation in extracurricular activities in higher education. Therefore, understanding and bringing visibility to extracurricular learning can have a positive impact on students' development of professional identity and employability. However, making student learning gains explicit requires implementing strategies to help students bring to the surface learning gains they might be unaware of (van Uum & Pepin, 2022). Moreover, there is a challenge for higher education institutions to effectively support learning in highly open, self-directed environments, such as that of extracurricular student teams, and for students to self-direct their learning.

Considering this context, TU/e innovation Space has initiated a three-year, design-based project, which aims at improving students' understanding of their extracurricular learning and competence development. Specifically, the project aims at making extracurricular learning more visible and explicit for students, guiding their learning and development while participating in extracurricular student teams. Importantly, the project aims at making a clearer link between the extracurricular activities and students' development of their professional identity, which include domain-specific (i.e., disciplinary) competences, broad professional competencies, but also their personal values and aspirations.

In this paper, the results of a first, exploratory phase in the design-based project (i.e., problem exploration) are reported. Based on in-depth interviews with alumni from extracurricular student teams we aim to answer the following research question: What do students learn in extracurricular student teams?

The remaining part of this paper is structured as follows: First, we provide the theoretical framework guiding our research. Subsequently, we elaborate on our methods, and we present the results. Finally, we conclude with a discussion on the findings.

THEORETICAL FRAMEWORK

The aim of this study is to find an answer to the research question, "What do students learn in extracurricular student teams?" To achieve this, first we need to define the concept of learning gain and, second, the concept of competence.

In this work, we define *a learning gain* as "a student's change in knowledge, skills, attitudes, and values that may occur during higher education across disciplines" (Vermunt et al., 2018). 'Learning gain' relates to the concept of *competence,* which is defined by Edwards-Schachter et al. (2015) as follows: "competence identifies both the combination of related traits, knowledge, values, attitudes, and abilities embedded in determined context and the process of development of them as an integrative personal construct". In connection with this definition, we also consider that the development of competences occurs in a learning process launching from potential capacities, involving traits, knowledge, abilities, and attitudes, and advances progressively integrating capacities (be able to) in specific contexts (Edwards-Schacter et al., 2015). Therefore, learning gains on skills, knowledge, attitudes work as building blocks for the development of competences.

Several existing frameworks provide insights into the various competences students can develop in the context of higher education (e.g., EntreComp, Bacigalupo et al., 2016; EUR-ACE, EUR-ACE, 2021; Academic Criteria for Bachelor's and Master's Curricula, Meijers et al., 2005; Bartram's Framework, Bartram; 2005). In this study, the CDIO Syllabus revision 3.0 (Malmqvist et al., 2022) guides our understanding of students' learning gains and competences reported by students. The reason for the decision is twofold. First, the CDIO syllabus presents in its four sections (fundamental knowledge; personal and professional skills; interpersonal skills; conceiving, designing, implementing, and operating abilities; and the expansion) detailed descriptions of learning outcomes that can be used to code what students self-report. Secondly, in the expansion section, detailed descriptions of learning outcomes associated with leading engineering endeavors, entrepreneurship and research, are presented (Malmqvist et al., 2022). These are relevant for this research given the characteristics of the extracurricular projects executed by student teams at the TU/e and the focus of TU/e innovation Space on promoting the development of these areas of expertise.

METHODOLOGY

In this exploratory investigation, semi-structured in-depth interviews were selected as the method to gather students' perspectives on their learning gains, as they can provide richer details (Immekus et al., 2005; Eichman et al., 2015). Five students were purposefully selected from different student teams to be interviewed for 45–60 minutes. The selection criteria required that the alumni participate for more than one year on a student team; they didn't participate in the same team; and they participated in teams solving different challenges. Participants joined voluntarily. The interviews were conducted live and voice-recorded after students signed a consent form for participation.

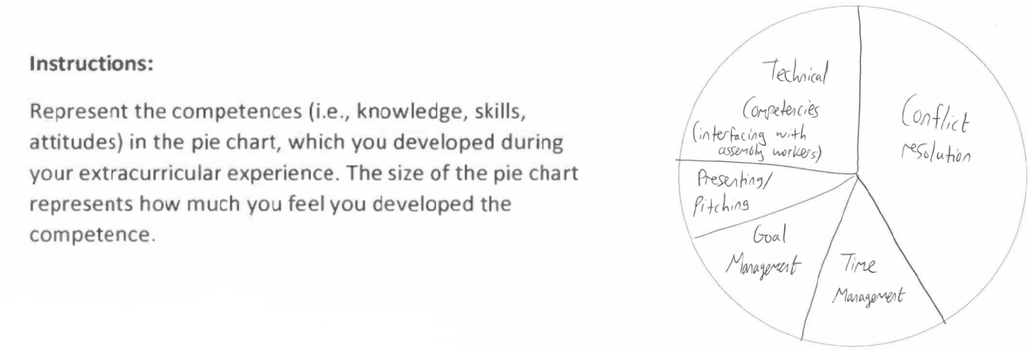
An interview guide was developed to guide the inquiry with participants, and designed to gain a better understanding of students' motivation to join a team, their learning, how they developed it, and their perception of the relevance of their learning. The competence concept is used in the interviews because it refers to the result of a learning process, which includes learning gains (Edwards-Schacter et al., 2015). In addition, terms such as attitudes and skills are not clear for students (Jorre de St Jorre & Oliver, 2018). Examples of the questions are:

a) *Tell us about what you feel you have learned during your time on the student team. Think out loud and walk us through the process.*
b) *Walk us through the learning you just identified. Where do you see this competence evident? Where did you need it? Where were you able to use it?*
c) *Provide examples of how you reached this learning/developed this competence: How did you develop it? Who or what was important in this learning? Which tasks were you able to do at the end of your participation in the student team but couldn't do at the start?*

Moreover, following the method proposed by van Uum and Pepin (2022), a pie chart was included in the guide, where every student was asked to represent their perceived learning gains or developed competences. In the pie chart exercise, the students received the following instruction: *Represent the competences in the pie chart, which you developed during your extracurricular experience. The size of the pie chart represents how much you feel you developed the competence.* An example of the pie chart is presented in Figure 1. Finally, students were asked to indicate the factors that influenced the growth of the indicated competences by clicking on boxes. The alternatives included: a) workshop, b) prior course of your program, c) students(s) in your team, d) academic consultant, e) industry or business consultant, f) internet source, g) by doing, h) by reflecting in team sessions, i) last's year team, j) outside support (friends, family, etc.), and k) others.

We only considered learning gains or the development of a competence when the student explicitly indicates that he or she has gained more insight into or understanding of his or her own performance on or mastery of competences, as Bakkenes et al. (2010) did in previous works. Other expressions were excluded in this exploratory phase.

Figure 1. Pie chart example



DATA ANAYSIS

The data analysis consisted of three steps. First, interview transcriptions were read, and the sentences where students explicitly indicated that they gained more insight were marked. Also, examples of tasks that students indicated they were able to do at the end of the project but couldn't do at the start were considered. Second, interview transcript quotes were coded in relation to CDIO syllabus 3.0, associating the contents of transcribed sentences with competence. The information included in the pie chart was also included as interview information. Third, codes were counted and grouped under the main CDIO syllabus 3.0 categories: fundamental knowledge; personal and professional skills; interpersonal skills; conceiving, designing, implementing, and operating abilities; and the expansion, which includes leading engineering endeavors, engineering entrepreneurship, and research. Thus, we will see what competences were mostly reported.

RESULTS

In this section, the results are presented in the form of portraits; the names of the students were changed to pseudonyms to ensure anonymity. The findings from the interviews are supported by representative quotes that are intended to be illustrative.

Portrait of Gert

Gert is a student of biomedical engineering at TU/e. When consulted about his motivations to join a team, he expressed:

One of my friends was already in the organization. So, I joined a couple of meetings. I found it very interesting. That's why I joined. And also, because I had some spare time in a week. So, it was great!

The team's objective is to organize a student competition where teams from all over the globe develop innovative biosensing systems. Gert was responsible for organizing the whole competition week and ensuring that all the activities ran smoothly.

Gert's learning expectations were: increasing meeting skills, developing professional skills, learning how to write emails, connecting with companies, and learning how to talk to professionals. After his participation, his learning expectations were surpassed.

In the pie chart exercise, Gert indicated and ranked the competences according to how much he felt he developed them as follows: a) risk management, b) meeting efficiency, c) professional contact, d) reduction of calling fear, e) biosensors. Gert indicated that these learnings were promoted by self-reflection, peer feedback, and observing and selecting other people's good practices to integrate into his work process.

Finally, Gert indicated that he knows he learned many things, but he has difficulties expressing them in a detailed way.

Portrait of Lena

Lena is a management student at a university of applied sciences. She joined a student team because she was looking for a place to do her internship. In that process, one of the TU/e student teams offered a position to manufacture a machine for a specific market need.

Lena joined a team whose objective is to improve the most challenging branches of the recycling industry, working on e-waste recycling and breaking it down to raw materials. She described her expectations as follows:

A lot of learning, a steep learning curve, a lot of mistakes, and eventually delivering a product that could change the world or the industry.

When asked if her expectations had been met after two years on the team, she replied:

The steep learning curve and the possibility to learn most certainly, the project still hasn't changed the world.

The role she performed was first technical while she was building the machine, and then, when she earned a minor in management, she took on a role associated with management. In her technical role, she had to design, build, and test a machine to recycle mobile batteries. In her managerial role, she had to research different management structures and analyze how they could be applied to the team.

In the pie chart exercise, she indicated and ranked the competences according to how much she felt she developed them as follows: a) research, b) critical thinking, c) working in teams, d) managing a team, e) business structure, f) doing experiments, and safety. Lena reported that most of these learnings were promoted by team members' interactions, by doing, and by workshops organized by her team.

Lena explained that she is very fluent when it comes to expressing her learnings because she has always been an easy talker who says exactly what she is thinking.

Portrait of Max

Max is an industrial design master's student. Max indicates that when he joined the team, he had no expectations regarding learning. His motivations were mainly related to social aspects:

I liked the challenge of having this huge group of students, all multidisciplinary, all types of students, working together towards one goal. I really enjoy working on projects with a big group.

Max joined a team whose objective is to design and build sustainable cars. His role in the team was social media manager. He participated in this role for one year.

In the pie chart exercise, he indicated and ranked the competences according to how much he felt he developed them as follows: a) social aspects, b) professional behavior, c) myself, d) social media, e) cars, technical knowledge, f) Adobe. Max reported that most of these learnings were achieved via peers, by doing, through external support, and as a result of workshops.

Finally, Max indicated that he recognized that he learned a lot, but explaining clearly what he learned is difficult.

Portrait of Anna

Anna did her bachelor's in industrial design and then followed innovation management. She has always wanted to run her own business and was never swayed by the traditional course structure. She did the challenge-based, on-campus, master team-based project. Once there, she identified the opportunity to transform the project outcome into a start-up. This company develops cognitive training for different areas, such as sports and the health sector.

Anna's role involved making strategic decisions for the company, creating business models, managing finances, and being responsible for work processes.

Anna, when asked about her opinion about her experience on the team, said that she enjoys being part of the team and that she feels it is like a hobby.

In the pie chart exercise, she indicated and ranked the competences as follows: a) internal management, b) being flexible, c) communication (presenting, pitches, networking), d) building confidence, e) regulation and finances, and d) managing people. Anna reported that most of these learnings were promoted by peers, by doing, by business consultants, and by workshops.

When consulted about how difficult the process of recognizing learning gains or the development of competences is, she answered:

After I learned something or didn't, in my bachelor or master, and I look back on what I learned, I don't really feel like that I learned anything because you don't really know what you knew before that experience.

Portrait of Helena

Helena follows the sustainable innovation master program. Her motivation to be part of a student team was to apply her bachelor's knowledge to an impactful project that lasted more than just a quarter. Her objective was to shape the team and the project.

Helena participated in a team whose objective was to design and build a sustainable, autonomous, and affordable rover to support research activities in Antarctica. She worked for the team for three years. The first year, she executed technical and engineering tasks; the second and third years, she executed managerial tasks.

In the pie chart exercise, she ranked the competences as follows: a) team building, b) learning how to learn, c) external relationships, f) identifying and assessing problems and priorities, g) presenting, and h) computer aided design, CAD. She indicated that these learnings were promoted by doing, by peers, by outside support (family), by an academic consultant, by workshops, and by internet tutorials and resources (TED talks).

Lastly, Helena indicated that she learned many things, but she thinks that describing her learnings with clarity is difficult.

Table 1 shows an example of the competences identified, and Table 2 shows a summary of the number of competences counted. The complete data are indicated in Appendix A.

Table 1. Competence identified after coding - example

Student	CDIO sec.1: Fundamental engineering knowledge	CDIO sec.2: Personal and professional skills and attributes	CDIO sec. 3: Interpersonal skills	CDIO sec. 4: Conceiving, designing, implementing, and operating	CDIO sec. 5: Leadership, entrepreneurship, and research	Competences not included in CDIO syllabus 3.0
Lena	Advanced engineering fundamental knowledge methods and tools	Critical thinking; Motivation for continuing self-education; Experiments planning; Experimental and knowledge discovery; Self-awareness; Information search; Personal vision on one's future; Time and resource management; Self-direct learning	Establishing diverse connections and networking; Forming teams, assigning roles and responsibilities; Handling diverse perspectives and conflicts; Coordination of team meetings; Oral presentation; Pitching; Planning and scheduling the work; Setting goals and objectives; Working in teams	Designing, recycling; Disciplinary design; Enterprise and business context; Safety and security; The research and technology development process; Utilization of knowledge in design	Business plan development; Creating new solution concepts; Defining the solution; Identifying the issue, problem; Thinking creatively and communicating possibilities	How to work in teams that provided services/products in Business to Business setting; Knowledge on how business to business works

Table 2. Number of competences counted after coding

Student	CDIO sec.1: Fundamental engineering knowledge	CDIO sec.2: Personal and professional skills and attributes	CDIO sec. 3: Interpersonal skills	CDIO sec. 4: Conceiving, designing, implementing, and operating	CDIO sec. 5: Leadership, entrepreneurship, and research	Competences not included in CDIO syllabus 3.0
Gert	1	3	5	0	0	0
Lena	1	9	9	6	5	2
Max	1	5	5	2	1	2
Anna	0	6	7	6	9	0
Helena	0	9	11	2	1	0
Total	3	32	37	16	16	4

DISCUSSION AND CONCLUSIONS

In this research project, we set out to explore what students learn in the extracurricular projects at TU/e. The research project is a first step in a three-years design-based project, aimed at making extracurricular learning more explicit. Our results identified that most of the learning gains reported by the five students, in both the pie chart and in the analysis, were associated with personal and professional skills (CDIO syllabus section 2) and interpersonal skills, collaboration, teamwork, and communication (CDIO syllabus section 3). Leadership, entrepreneurship, and research (CDIO syllabus section 5), and conceiving, designing, implementing, and operating (CDIO syllabus section 4) were reported with higher frequency in the case of two students who performed specific roles that exposed them to situations that promoted the development of those. Learning associated with content knowledge (CDIO Section 1) was reported only by one student in the pie chart and appeared three times after analyzing the coding results. From this finding, we infer that a possible relationship exists between the roles in the team and the learning gains reported by students.

While not our primary goal, our research also led to insights into how students learn in the context studied. When students were asked to indicate the factors that influenced the development of their self-reported learning gains, they reported them in order of relevance: by doing, team peers, and workshops. Other methods were reported less often. From this result, we conclude that most of the learning occurs while working in the team on their projects, and in day-to-day interactions with peers. However, team activities are disconnected to premeditated learning objectives, which could possibly explain why learning is not explicit for students. When asked how easily they identify learning gains or the development of competences, students indicated that they can identify the development of competences during their participation in student teams. However, they find it difficult to identify those learnings precisely. This is in line with what was reported by van Uum and Pepin (2022), who indicate that students might develop certain competences that they are not aware of.

In addition, the number of learning gains reported in the pie chart is lower than the number detected after analyzing the coding. For example, Lena reported working in teams as a learning gain in the pie chart. However, after analyzing her interview coding, we detected learnings associated with two CDIO syllabus learning outcomes: (a) forming teams, assigning roles, and responsibilities; and (b) coordination of team meetings. Both are subcategories of working in teams. From this result, we hypothesize that a) student descriptions of learning gains could be limited by their vocabulary, b) students are not aware of some learning gains that they might experience, and c) some learning gains are not immediately relevant for them, therefore, although they experience them, they do not report them.

Overall, we can conclude that students in extracurricular student teams experience learning gains which are associated with CDIO learning outcomes. However, making students' learning visible is still a challenge in this context where intended learning outcomes are not defined a-priori, and the learning path of a student in a certain team is not well understood yet.

Limitations and future work

Several limitations can be reported in connection with this exploratory research. First, the use of self-reporting as a unique source of information to gather student-perceived learning gains could have an impact on the validity of our findings. Including other instruments, such as observations, surveys, and reflections could help increase the soundness of information and the validation of students' self-reported learning gains. Second, we decided to consider as learning gains only those quotes where the students explicitly indicated that they had gained more insight into, or understanding of, their own performance or mastery of competences. However, literature includes other learning categories where the students report they have gained, through the learning experience, more understanding on how a skill works, or express a positive change in their perception of the value, importance, or significance of a generic skill (van Ravenswaaij et al.,2022). Third, the participation of only student teams' alumni, which could lead to a specific set of learning gains, and a weaker link to contextual information relevant to understand *how* extracurricular students develop their learning.

The work presented in this paper also informs future research and actions in our three-year design-based project. Of particular interest is the acquisition of content knowledge through the extracurricular learning experience, which was not prominently listed as a learning gain by students. Future work could therefore explore students' views on extracurricular learning in relation to the learning in their own programs. In the next steps, we will focus on further exploring learning and competence development in extracurricular teams and how to make it visible or explicit through a mixed-methods approach, such as surveys, observations, and co-creation sessions. Future work should also expand on the number and diversity of students to be interviewed. In this regard, we recommend including active members of different student teams who play different roles on them. In addition, we recommend adding additional categories to detect a learning gain or the development of competences based on the work of van Ravenswaaij et al. (2022) and Bakkens et al. (2010). Finally, we propose performing a more detailed study to understand how peers' interactions and work in the team, without a premeditated learning objective, promote learning gains and the development of competences.

Our ongoing research already takes the above insights into account and dives deeper into the topic of extracurricular learning through case studies of sampled student teams. We expect this approach will allow us to map in more detail the roles within student teams, the learning ecosystem in general, the team processes and outcomes, and their connection to learning. Performing these and future research activities will help to improve the characterization of the learnings experienced by student teams' members. This will provide better tools to suggest specific learning paths and resources to students when they want to develop or acquire specific competences. Finally, these best practices could impact positively and make more effective the design of Challenge-Based Learning experiences in the curriculum.

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Appendix A – Interviews analysis outcome

Student name	CDIO sec.1: Fundamental engineering knowledge	CDIO sec.2: Personal and professional skills, & attributes	CDIO sec. 3: Interpersonal skills	CDIO sec. 4: Conceiving, designing, implementing, operating	CDIO sec. 5: Leadership, entrepreneurship, & research	Competences not included in CDIO syllabus 3.0
Gert	Advanced engineering fundamental knowledge methods and tools	Adaptation to change; Professional behavior; Self-confidence, courage and enthusiasm, determination to accomplish objectives	Communication: communication context; Communication: the needs and character of the audience; Coordination and management of the team process, meetings; Forming teams, assigning roles and responsibilities; Working in teams	Not reported	Not reported	Not reported
	Total: 1	Total: 3	Total: 5	Total: 0	Total: 0	Total: 0
Lena	Advanced engineering fundamental knowledge methods and tools	Critical thinking; Motivation for continuing self-education; Experiments planning; Experimental and knowledge discovery; Self-awareness; Information search; Personal vision on one's future; Time and resource management; Self-direct learning	Establishing diverse connections and networking; Forming teams, assigning roles and responsibilities; Handling diverse perspectives and conflicts; Coordination of team meetings; Oral presentation; Pitching; Planning and scheduling the work; Setting goals and objectives; Working in teams	Designing, recycling; Disciplinary design; Enterprise and business context; Safety and security; The research and technology development process; Utilization of knowledge in design	Business plan development; Creating new solution concepts; Defining the solution; Identifying the issue, problem; Thinking creatively and communicating possibilities	How to work in teams that provided services/products in Business to Business setting; Knowledge on how business to business works
	Total: 1	Total: 9	Total: 9	Total: 6	Total: 5	Total: 2
Max	Advanced engineering fundamental knowledge methods and tools	Professional behavior; Professional conduct in social media; Search and identification using library, on-line, data bases; Self-awareness and self-reflection; Self-confidence, courage, and enthusiasm to accomplish objectives	Communication, needs and character of the audience; Communication strategy; Meeting coordination; Use of digital tools for graphical communication; Working in teams	Enterprise stakeholders, strategy and goals; Experimental prototypes and test articles in design development	Planning an managing a project to completion	Communicating the concept and meaning of a brand; Creating a brand
	Total: 1	Total: 5	Total: 5	Total: 2	Total: 1	Total: 2
Anna	Not reported	Adaptability resourcefulness and flexibility; Balance between personal and professional life; Initiative and willingness to make decisions in the face of uncertainty; Professional behavior; Prioritization and focus; Self-confidence	Communication strategy; Coordination and management of team processes; Establishing diverse connections and networking; Negotiation, compromise and conflict resolution; Oral presentations; Setting norms about confidentiality; Working in teams	Enterprise strategy and resource allocation; Engineering project finances and economics; Entrepreneurial finance and organization; Enterprise stakeholders, strategy and goals; Partnership and alliances; Working effectively within hierarchy and organization	Business plan development; Establishing enterprise processes; Company capitalization and finances; Consideration of regulatory forces; Creating the corporate entity and financial structure; Conceiving products and services around new technologies; Leading and building an organization; Managing intellectual property; Relationship with customers	Not reported
	Total: 0	Total: 6	Total: 7	Total: 6	Total: 9	Total: 0
Helena	Not reported	Ability to examine critical questions; Critical thinking; Finding a solution that solves the problem; Information search and identification using library, on-line, and data based tools; Issue prioritization in context of overall goals; Personal vision for one's future; Problem identification and formulation; Self-awareness; Self-directed learning	Coordination and management of the team process; Creativity, empowerment and motivation; Coordination and management of team processes, communication-information; Forming teams, assigning roles and responsibilities; Handling diverse perspectives and conflicts; Working in teams; Oral presentations; Setting goals and objectives, planning, scheduling the work; Stakeholder engagement; Team membership and leadership; Use of digital tools for graphical communication	Utilization of Technical and scientific knowledge; Validation of performance to customer needs	Validation of performance to customer needs	Not reported
	Total: 0	Total: 9	Total: 11	Total: 2	Total: 1	Total: 0

STUDENT-CENTERED LEARNING ACTIVITIES FOR KEY SUSTAINABILITY COMPETENCIES IN ONLINE COURSES WITH MANY STUDENTS

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ABSTRACT

Engineers can make a valuable contribution for a transformation towards a sustainable society. The CDIO framework, where student-active and integrated learning is intrinsic to design-implement activities, therefore also includes sustainability competencies. The purpose of this paper is to evaluate alignment between specific student-centered (active) learning activities used in digital learning environments with many students and engineering competencies for sustainability. Examples of learning activities in two such online courses are presented and evaluated in comparison to the UNESCO key competencies for sustainability. The courses are two undergraduate courses at NTNU where sustainable engineering represents the discipline knowledge. The learning activities were designed for scalability and to be operable within an entirely digital learning environment. The student-centered learning activities that are used in the courses are: i) project-based learning, ii) academic text with peer-review, iii) auto-graded computational assignments, iv) massive online course module, v) flipped classroom. We outline the design of the learning activities and map their alignment with abilities within key sustainability competencies. We discuss the effects of scalability and digital format on learning outcomes, and the student feedback and plans for further development.

KEYWORDS

Engineering education, Systems thinking, Student-centered, CDIO Standards: 1, 2, 3, 6, 7, 8, 11, optional standard 1

INTRODUCTION

There is an urgent need for transformation of society towards sustainable development. Governments all over the world have adopted the UN 2030 Agenda and agreed on the Sustainable Development Goals (SDGs) (UN, 2015). Engineers have a critical role and can make a valuable contribution to such a transformation and therefore engineering education must be designed to support learning of sustainability competencies. In line with these needs, the CDIO framework for engineering education has been updated to include sustainability. Sustainability is now explicit in most of the twelve core CDIO Standards 3.0 (Malmqvist, Edström, & Rosén, 2020a) and in addition there is an optional standard for sustainable development (Malmqvist, Edström, Rosén, et al., 2020b). This makes an important difference since these standards define the distinguishing features of a CDIO program, serve as guidelines for educational reform, enable benchmarking with other CDIO programs and provide a tool for self-evaluation-based continuous improvement. In line with this change of the Standards, the CDIO Syllabus has been updated to version 3.0 and sustainability is now integrated to a larger extent than before (Malmqvist et al., 2022). The CDIO Syllabus is a list of topics that indicate desirable competences of graduating engineers that can be used as a source of inspiration or as a frame of reference, for instance when selecting and formulating learning outcomes for curricula and courses.

The update of the CDIO Syllabus 3.0 was preceded by an evaluation of the CDIO Syllabus 2.0 compared to the Unesco key competencies for sustainability (Rosén et al., 2019). The integration of sustainability into the CDIO Syllabus 3.0 was then to large extent influenced by these key competencies for sustainability but also by other key competency frameworks (EOP, 2020; Lozano et al., 2017; Wiek et al., 2011, 2016).

According to constructive alignment (Biggs & Tang, 2007), learning activities in a course should be designed to activate students and support their learning of the intended learning outcomes for the course, i.e., students should practice on what they should be able to do. Another way to frame this intention is that the teaching should be *student-centered*. Student-centered teaching places more of the learning responsibility to the student (Wright, 2011), allowing students to take control of the learning by active participation, or self-education. Thus, a challenge for teachers is how to design appropriate learning activities to support key competencies for sustainability. Examples of appropriate learning activities can be found in previous research on education for sustainable development within MPhil (Cruickshank & Fenner, 2012) and engineering programs (Segalàs et al., 2009).

Digital learning environments represent an additional challenge for student-centered learning. The digitalization of education was accelerated due to the corona pandemic and online teaching is still used occasionally also in campus located education and is promoted when the pedagogical benefits are considered to dominate compared to classroom teaching. Another constant pressure on universities, due to economic reasons, is to deliver education in a more resource-efficient way, which can influence the number of students that are expected to take a course at the same time. One benefit of online courses is that they can be scalable, i.e., have many students. Hence, there is a need for good examples of appropriate learning activities for key competencies for sustainability in the setting of online courses with many students.

In this paper, we describe several student-centered learning activities that have been used in courses to support key competencies for sustainability. The activities have been employed in two undergraduate courses at the Norwegian University of Science and Technology (NTNU). The courses cover sustainable engineering, have been given in a digital format, and serve 250 and 1000 students respectively. Our aim is to discuss the scalability of the individual learning activities and to evaluate the extent to which the intended sustainability competencies can be fulfilled with the portfolio of activities. To do this we conduct an initial, qualitative mapping of the applied student-centered learning activities towards UNESCO's key sustainability competencies and affiliated abilities. We proceed to discuss the principal alignment of the scalable activities towards abilities, based on qualitative considerations, literature and specific student feedback. To aid any study program seeking to integrate competencies for sustainability in activities and learning outcomes within a CDIO framework, we include a short description of the learning activities and how they relate to the CDIO Standards. Finally, we summarize student feedback and potential further development of the activities.

BACKGROUND

The courses in our case are described in Table 1 and the course content can be described as *sustainable engineering*. Both courses were conducted at NTNU entirely within a digital learning environment in 2022, entailing primarily group work and activities suited for self-guided and student-centered learning. The specific learning activities follow the table.

Table 1. The Courses

Course	Brief context and description
TEP4295 *Sustainable engineering*	An undergraduate course at 7.5 ECTS offered to 2nd and 3rd year students in 5-year integrated MSc programs, in total 200-250 students. The course covers concepts, assessment methods and strategies for sustainability. The course has been transformed from a teacher-oriented format last lectured in spring 2020, to a fully online version in 2021 and 2022 as a hybrid (streamed) course in 2023.
INGX2300 *Engineering systems thinking*	An undergraduate course at 10 ECTS offered in the final semester to all NTNU's bachelor engineering programs, in total 1 000 students divided between three campuses (Trondheim, Gjøvik, Ålesund). The course covers innovation, entrepreneurship, economic management, and sustainable engineering. The course has been conducted as one digital, shared course across all study programs since spring of 2022.

Project-Based Learning (INGX2300), where students work in inter-disciplinary groups of 5-6 members to develop new business concepts within a given theme (Energy storage, Smart City, etc.). The project requires creativity and strategic thinking to develop a business concept, and discipline knowledge from the course to evaluate market and sustainability potential of their concept. Scenario-thinking is specifically asked for in this assignment. The project assignment includes several deliverables over the 8-week period, amongst them is a collaboration agreement, midterm oral pitch, and final report.

Academic Text with Peer Review, where students write a short academic text (1000-1200 words) about definitions of sustainability and how the students consider sustainable engineering to be relevant for their profession. They provide anonymous written feedback to their peers on draft papers, before revising their own paper based on the rubric comments they receive themselves. Peer assessment is facilitated by a commercial online education management system (*Eduflow*), for the papers as well as in group assignments to correct and comment on a rather strictly defined scenario model exercise (TEP4295). Direct peer feedback is also applied, wherein the student groups comment orally on pitch presentations of their peer groups' business in the project-based learning activity (INGX2300).

Auto-graded Computational Assignments, made using *nb-grader*, a tool to make and grade Jupyter Notebooks (Jupyter et al., 2019). *Training notebooks* are setup with local, instant feedback and contain mimicked examples from the textbook, including video material and textbook links. *Assignment notebooks* are graded on the central server with 60 min delay to avoid overload. All assignments are identical with seed randomization and solving them

involves programming and linear algebra. Students are encouraged to work together to solve the problems as no student will share the same numerical solution.
Massive Online Course Content holds the non-computational curriculum. Built using *Eduflow*, it contains reading and video material for self-paced individual and group study. The format allows a combination of ways to illustrate and teach core sustainability concepts and strategies, through reflection questions, discussion boards, quizzes, etc.

Flipped Classroom Problems, in-class activity (Akçayır & Akçayır, 2018) and spaces to discuss and reflect contents of the online course module and computational materials. Each session is described in the course learning platform outlining i) preparatory video and reading material, ii) problem description, and iii) digital tools, iv) digital channels for audio/video and written communication. Both tailor-made (simplistic databases for life cycle assessment and input-output analysis) and third-party tools (climate policy simulator) are used in the flipped classrooms. The problems include simplified life cycle assessment (plastic and natural Christmas trees), allocation in life cycle assessment (milk farm), material flow analysis (clothes in Norway), carbon footprint (of a student), energy assessment (windfarm concept), industrial symbiosis (for a specific industry cluster), and global climate policy (how to stay under 1.5 degrees). The flipped classrooms have been conducted in purely online formats (INGX2300) and hybrid streams (e.g., TEP4295 in 2023). Online video communication platforms are used to initiate the session, provide the online workspace (Zoom), and communication channel (discussion board).

METHOD

Qualitative mapping was conducted to evaluate alignment between the learning activities towards the intended sustainability competencies and affiliated abilities in Table 2. We use the UNESCO key competencies for sustainability. These have largely influenced how sustainability is integrated in the CDIO Syllabus 3.0, and have beenderived by synthesis of published sustainability education research (Haan, 2010; Rieckmann, 2012; Wiek et al., 2011).

We aim to discuss the scalability of the learning outcomes, i.e., how well the outcomes can be supported when conducting the activity for many students. The discussion is based on theory from literature and qualitative considerations from the teacher's own observations, using for review and interpretation student feedback received from the last two years. There has been written feedback from the students in completed surveys as well as oral feedback in dialogue with the class and class representatives during course evaluation. Large variation in exam format over the last three years hamper a more quantitative assessment of learning outcomes.

Finally, in the evaluation of the alignment of the learning activities to the CDIO Standards 3.0, the focus is on the content in the Standards about competencies and learning activities as well as sustainability.

Table 2. The UNESCO Key Competencies for Sustainability (Unesco, 2017)

No.	Competency	Related abilities
1	Systems thinking competency	a. recognize and understand relationships; b. analyse complex systems; c. think of how systems are embedded within different domains and different scales; d. deal with uncertainty.

2	Anticipatory competency	a. understand and evaluate multiple futures – possible, probable and desirable; b. create one's own visions for the future; c. apply the precautionary principle; d. assess the consequences of actions; e. deal with risks and changes.
3	Normative competency	a. understand and reflect on the norms and values that underlie one's actions; b. negotiate sustainability values, principles, goals, and targets, in a context of conflicts of interests and trade-offs, uncertain knowledge and contradictions.
4	Strategic competency	a. collectively develop and implement innovative actions that further sustainability at the local level and further afield.
5	Collaboration competency	a. learn from others; b. understand and respect the needs, perspectives and actions of others (empathy); c. understand, relate to and be sensitive to others (empathic leadership); d. deal with conflicts in a group; e. facilitate collaborative and participatory problem solving.
6	Critical thinking competency	a. question norms, practices and opinions; b. reflect on own one's values, perceptions and actions; c. take a position in the sustainability discourse.
7	Self-awareness competency	a. reflect on one's own role in the local community and (global) society; b. continually evaluate and further motivate one's actions; c. deal with one's feelings and desires.
8	Integrated problem-solving competency	a. apply different problem-solving frameworks to complex sustainability problems and develop viable, inclusive and equitable solution options that promote sustainable development, integrating the abovementioned competences.

RESULTS

Learning Activities and Alignment to Key Competencies for Sustainability

An evaluation of the learning activities and their contribution to key competencies for sustainability is presented in Table 3. Before a further description of the mapping, we make the observation that, looking across all learning activities, every individual ability is answered by at least one activity and most abilities align with more than one activity.

Table 3. Alignment of Learning Activity and UNESCO Key Sustainability Competencies

	Learning activity *Letters refer to related abilities under each competency. Abilities not aligned with the specific learning activity is marked in strike-through, red letters.*				
Sustainability competencies	Project-based learning	Academic text with peer review	Auto-graded computational assignments	Massive online course material	Flipped classroom problems
1.Systems thinking competency	a, b, c, d	~~a, b,~~ c, ~~d~~	a, b, ~~c,~~ d	~~a, b, c, d~~	a, b, c, d
2.Anticipatory competency	a, b, c, ~~d,~~ e	~~a,~~ b, c, ~~d, e~~	~~a, b, c,~~ d, ~~e~~	~~a, b, c, d, e~~	a, b, ~~c,~~ d ~~, e~~
3.Normative competency	~~a,~~ b	a, ~~b~~	~~a, b~~	a, ~~b~~	a, b

4.Strategic competency	a	~~a~~	~~a~~	~~a~~	a
5.Collaboration competency	a, b, c, d, e	a, ~~b, c, d, e~~	~~a, b, c, d, e~~	~~a, b, c, d, e~~	a, b, c, d, e
6.Critical thinking competency	a, b, c	a, b, c	~~a, b, c~~	~~a,~~ b, ~~c~~	a, b, c
7.Self-awareness competency	a, b, c	a, ~~b,~~ c	~~a, b, c~~	a, ~~b, c~~	a, ~~b,~~ c
8.Integrated problem-solving competency	a	~~a~~	~~a~~	~~a~~	a

From Table 3 is appears the massive online course module and the auto-graded assignments add only marginally to the competencies. The massive online course module does contain questions and tasks that require normative and critical thinking, and self-reflection. Student participation in these supplements their learning towards the affiliated competencies. Still, the online course material and the computational assignments are mainly discipline oriented and only to a very limited extent allow for competency integration. They may therefore be defined as pre-requisites for the other, more experiential activity. Still, the online format maximizes accessibility to the material and self-regulation of learning is supported when students can revisit the material multiple times, both in preparation of class and after (Jovanovic et al., 2019).

The format of the computational assignments allows for auto-grading and resource benefits. It facilitates grading of computational assignments in large courses, with an instantaneous or relatively fast response that is formative in nature and supports self-paced learning. The computational assignments include analysis of systems and system relations at different scales (systems thinking competency), including models of consequences of actions (anticipatory competence). The format of the assignments is similar to the *many small programs*-concept that has been found to be able to improve course experience, reduce stress and improve fulfillment of learning outcomes (Allen et al., 2018).

Integrated problem-solving competency, i.e., the opportunity to combine and develop all specific competence areas, is only represented in the problem-based activities, thus in the project work and the flipped classroom sessions. Besides supporting the key competencies, problem-based learning can benefit content knowledge, learning strategies, skills and motivation (Guo et al., 2020). The project-based activity is intended to allow students to apply integrated learning in a concrete case, with emphasis on innovation and entrepreneurial efforts. The groups are asked to evaluate and negotiate sustainability and market aspects, thereby also reflecting on values and perceptions and take a position (i.e., critical thinking competency). The project-based approach has been proposed as particularly relevant for sustainable development in engineering education (Lehmann et al., 2008). The project activity includes midterm presentations wherein groups present their concepts to each other and the teacher for feedback, supporting the ability to continually evaluate and further motivate one's actions.

Peer assessments can provide resource savings for the teacher. Few studies apply peer assessment in comprehensive learning environments such as collaborative work and problem-based learning (Ashenafi, 2017), which is unfortunate as peer feedback can increase student engagement in a task (Barroso & Morgan, 2011). It can make students think longer about the input they receive (and give), which is found to facilitate deep learning on the discipline concepts (Filius et al., 2018). Moreover, it gives experience in review as part of the systems engineering protocol. Peer assessment is also applied in the academic text that students write, which – although anonymous – allows learning from each other (i.e., collaboration competency). Peer review also requires engaging in normative and critical considerations and reflection on own roles and perspectives, thus supporting many key competencies.

The flipped classroom sessions allow for integrated problem solving and therefore link with most of the competence abilities. In one of the flipped classrooms the student groups are assigned a random country. They should then gather sustainability information about the country, such as human development index, gross domestic product, energy and health statistics, after which they are asked to negotiate within their group a global policy for achieving the Paris target of 1.5 degrees considering these other 'national' sustainability interests and needs. Policy strategies are tested and validated using a global climate policy simulator (En-ROADS). Finally, groups present their policies in open plenary and discuss them from the perspective of the countries present. The climate policy example, as well as the other flipped classroom activity, involves applying a holistic perspective and considers system effects of element changes (i.e., systems thinking competency). Moreover, it requires understanding and negotiating views and values, i.e., normative competency. The flipped classroom sessions should provide a critical and integrated dimension (problem solving competency) to the curriculum through peer-assisted, collaborative, and cooperative learning activities (which should develop their collaboration competency). Although many complete the tasks individually, the activity is designed as group work to think strategically about sustainable development (i.e., strategic competency). The design of the activity allows them to question norms and opinions (normative competency). Two of the flipped classroom problems involve the role of citizens and consumers, offering a venue to reflect on the role of local and global communities (i.e., self-awareness competency). The flipped classroom sessions thereby answer to most of the key engineering competencies, where the full list of alignments towards the UNESCO competency abilities is outlined in Table 3. The flipped classroom sessions require development of relatively simple system representations or use of predefined simulation models. These are to a lesser extent linked with anticipatory competency; given that they do not consider precautionary measures and risks, and in self-awareness competency; given that their policies concern other citizens.

Generally, the use of problem-based assignments can enhance capacity for flexible knowledge with new information acquired through self-directed learning (Bishop & Verleger, 2013). Flipped classroom can help build a positive social learning environment (Steen-Utheim & Foldnes, 2018). This is highly useful in a course such as the ones we describe here since it brings together multiple student groups, but experience also shows that it is more difficult to conduct in purely digital settings (Kim et al., 2014). Concrete feedback from the students was that they would strongly prefer to have a physical venue for the flipped classroom. They also pointed to success factors reported by others for flipped classroom (Gilboy et al., 2015; Rotellar & Cain, 2016): more clear and concise pre-class preparations (what should be known, not what should be done), use of check-in assessment (quiz or checklist), and a suitable work effort within the given time window, and effective digital and other in-class learning materials.

CDIO Standards

This section references first the alignment between the learning activities and the CDIO Standards 3.0, followed by a short discussion of relevance for Optional Standards 3.0.

The discipline knowledge in the courses is in support of environmental, social and economic sustainability knowledge in the context of engineering education (Standard 1: The context), supporting the rational that for engineers to contribute to develop appropriate technical solutions they need to understand the implications technology has on sustainability factors (Standard 2: Learning outcomes). The student-centered learning activities are particularly relevant for personal skills, and through collaborative and peer-to-peer evaluation to develop concepts, competencies, and interpersonal skills (Standard 3: Integrated curriculum).

Learning workspaces, especially the digital learning environment, is intrinsic to the cases that we describe (Standard 6: Engineering learning workspaces). Activities are conducted within digital environments and use various digital tools, with problem-based cases providing integrated learning experiences (Standard 7: Integrated learning experiences). The open, interdisciplinary problem-based assignments are student-centered and experiential (Standard 8: Active learning). The experience from conducting these exercises in the course is that the non-disciplinary learning is more challenging to achieve and leading to most of the practical obstacles (peer feedback, group formation, role clarification, collaboration agreements, fair distribution of workload, etc). According to Standard 8, teaching and learning should be based on active and experiential learning methods to engage students directly in thinking and problem-solving activities. A variety of learning assessment methods is applied, including formative sense peer-to-peer evaluation, quizzes, auto-grading and oral feedback, and as summative the final exam and the final report (Standard 11: Learning assessment).

The learning activities can contribute significantly to the fulfilment of CDIO Optional Standards 3.0, as they allow students to meet a course rich with sustainability learning experiences (Optional 1), apply simulation mathematics (Optional 2), and work with engineering entrepreneurship (Optional 3), all of which are competencies required to address sustainable engineering.

DISCUSSION

Scalability of Student-centered Activity and Key Abilities

Rather than one-way communication from an active teacher to passive students, student-centered learning practices shall engage students in autonomous learning and active participants in the learning process, as individuals and groups (Jones, 2007). Scalable student-centered learning activities are operable also with large student numbers and should encourage durable and deeper learning through promotion of important life-long learning competence such as growth mindsets, self-efficacy, and self-regulation, all of which also increase student retention and success (Hempel et al., 2020). We can easily confirm that these outcomes align with the sustainability competencies in Table 2, including collaboration competency (learn from others) and self-awareness (deal with one’s feelings and desires).

The activities in Table 3 are designed for scale, i.e., they should facilitate close to endless number of students. With the online platform, peer review is highly scalable, while also enhancing active, reflective, and participatory learning (Colbert & Arboleda, 2016). Similarly, the massive online course material and the auto-graded computation assignments have no limitation except for managing and communicating registration and acceptance (and remind those that do not pass). This leaves the two project-oriented activities: the project-based assignment and the flipped classroom sessions. We start with the latter.

High-quality learning materials, experiential training workshops, and ongoing classroom-based and online support is key for success in scaling education programs, yet must also be followed by positive interaction and social participation in the learning activity (Colbert & Arboleda, 2016). There are challenges with achieving active participation in digital learning environments. Enforcing mechanisms, or positive alignment, may be used to improve participation, such as improving the pre-class and preparatory material (Han & Klein, 2019; Rotellar & Cain, 2016). Certain trades are made between the scalability of the online format and the benefits of physical meeting rooms, as described by Kim et al. (2014). In physical flipped classrooms, upscaling requires venues, as well as an increase in support form lecture assistants or conducting course parallels to handle the large student numbers. This is especially required INGX2300 which distribute across campuses.

The project-based assignment includes a final report that is graded. The student activity itself scales well and can be supported using digital platforms. Peer-review and collective evaluation is used for the midterm presentation, both are scalable, formative evaluations. The major limit for scaling the project-based assignment is the summative grading and project support.

Synthesizing Table 3 we find that excluding the problem-based activities, i.e., project-based learning and the flipped classrooms, all the abilities under systems thinking competency will be met by one of the other three activity types. Within anticipatory competency, ability 2a and 2e are only met by the project-based activities, and the same is seen for the normative competency 3b (negotiate values). To support understanding of various futures (2a) and to deal with risks (2e) and trade-offs requires the involvement in the two less scalable activities. The same concerns strategic competency (4a), and most of the abilities under collaborative competencies (5b, 5c, 5d, 5e) except for learning from others. The three abilities within critical thinking competency are answered by the scalable activities in concert, as well as by the two problem-based activities. One of the abilities under self-awareness competency, 7b (evaluate and motivate one's action), and the integrated problem-solving ability (8a), is not answered by any of the scalable activities and requires either project-based activity or flipped classroom activity.

The TEP4295 course has been provided also as an online self-study course using the same learning materials. This implies that all parts of the course, including the flipped classroom sessions, can be conducted without synchronous and limited guidance. Students that follow the self-study version report lower motivation to complete the course. The grade outcomes are comparable in the online self-study and the conventional course formats, even if student numbers in the self-study course are too low to allow fair comparison. However, the lack of guidance and teacher attention is frequently pointed out by the students that feel that the outcome is limited by the digital format.

Student Feedback and Changes for Next Year

Student feedback provides a valuable input to further develop the activities and ensure alignment. This section summarizes the student feedback, as interpreted by the course administrator.

Students respond positively to the text assignment with peer review. They are frequently surprised by the request to write a subjective text in an engineering course, which many say they have not done since high school. In other words, the engineering students consider their field a technical and science-oriented one and extend this also to sustainable engineering. This emphasizes the need to integrate non-technical and organizational aspects into engineering education to better the competencies for sustainability (Segalàs et al., 2009). Another unexpected, yet more frustrating observation, is made by the students for the auto-graded computation assignments, when they realize they need to program in a course on sustainability. Arguably some of the assignments were in development into the course period and were also updated several times due to errors in the problems or solutions, causing students to question the correctness of the assignments and grader. We note here that self-efficacy may be specific to discipline, so that efficacy in one discipline does not necessarily transfer to another (Hempel et al., 2020). Having a growth mindset and self-reliance is important for life-long learning, and particularly so for sustainable engineering where future solutions must be different from those we see today. The need to learn technical skills, such as programming, to work with less technical problems, such as sustainability, makes for a very integrative learning experience. Changes to the computational assignments involve connecting them to the flipped classroom sessions, and these are described further below.

The massive online course material is generally received with positive feedback. It appears many students speed their way through the material and consider it a replacement rather than supplement for the textbook. The module contains also questions for reflection and discussion, discussion boards and quizzes, and many of these are not completed or the pedagogical effect of them is missed, indicating improvement potentials in the design, and perhaps also in the on-boarding of students. This observation supports what we stated earlier that the online course material rather can be considered a pre-requisite for the other learning activities rather than an independent activity.

The most appreciated activity is the project-based assignment. It offers the students freedom to pursue their own interest within the bounds of the problem and build an integrated and collaborative learning experience. Surveys confirm it is the assignment they invest most time in. It forms part of their summative grade, which for many of the students is highly motivating. A physical start-up was recommended after the first year in 2022, to initiate group formation and start the concept development.

The most challenging activity is the flipped classroom. The students are not provided with solutions for the problems presented in these sessions, although students generally ask for them. Active group formation is rather low, where few students end up working in groups and many do not complete the problems. The importance of alignment between the elements of a learning activity, and for flipped classroom also preparatory material, digital tools, problem description etc, is a recurring issue and has been reported by many (Gilboy et al., 2015; Reeves, 2006; Rotellar & Cain, 2016). Improvements to these will add to the value of the flipped classroom sessions. Many students reported frustration with not learning much from these sessions, and that they had to learn for themselves afterwards. It is well known that flipped classroom does not suit everyone and tends to polarize a class of students (Stöhr et al., 2020). On-boarding and building a consensus on the outcomes of flipped classroom is vital for it to activate students and support the intended learning outcome (Gilboy et al., 2015). A core conclusion from the feedback is to ensure buy-in and explain the connections between the integrated learning experience and sustainability competencies (Davidson et al., 2021). A very concrete opportunity to increase the perceived value of the flipped classrooms is to connect them to the computation assignments, principally making the computational assignments part of the preparatory material for the flipped classroom sessions. This can be seen as constructing a stricter alignment between the computational assignments (which involve the mathematics of sustainability assessment), and the flipped classroom activities (which focus on the concepts and theoretical aspects of the assessment methodology). Another concrete opportunity is to develop a form of check-in assessment to motivate preparation and reveal gaps. Both check-in quiz and integration with computational assignments were implemented for 2023. Feedback from the (hybrid) revised flipped classroom sessions in TEP4295 included the need to more concretely integrate anticipatory, normative and critical thinking, and allow more collaborative activity. As outlined above, the ultimate development of these competencies is hampered by the digital format. Further development should seek formats that involve increased dialogue and collaboration.

CONCLUSIONS

We identify many alignments between the student-centered learning activities and the full list of key sustainability competencies and related abilities in education for sustainable development. There are multiple connections between the activities, meaning that several activities match each ability. This can be seen as a strength in the courses, that the courses offer a portfolio of activities to support a multitude of sustainability competencies.

The major competence building is offered by the two activities that are more difficult to scale to many students, i.e., the project-based assignment and the flipped classrooms. Successful scaling of these will rely on better on-boarding students to the intention of the activities to let them take more active ownership of their education. Increasing the resource effectivity of education is a general challenge. Scaling higher education therefore is not a challenge specific to sustainability education, however, it is an area that is not well researched. The examples that we describe in this paper highlight that measures for successful scaling exist, e.g., auto-grading assignments and peer review. These measures also closely resemble what has been proposed elsewhere as measures to improve student success. Scalable student-centered learning activities should promote important life-long learning competence: growth mindsets, self-efficacy, and self-regulation (Hempel et al., 2020), which would also add to the resource efficiency of the activities. To revert to the idea of student-centered learning, it should involve practices to engage students in autonomous learning and active participation (Jones, 2007). Successful scaling of the activity require changes in both teaching and learning activities.

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MOTIVATION FOR CONTINUOUS SOFTWARE ENGINEERING EXPERTISE DEVELOPMENT THROUGH LIFELONG LEARNING

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ABSTRACT

It is important for software developers to keep up with technology, be able to adapt, learn new things to be competitive in the labour market, and be exposed to new and different things to avoid getting stuck in their old roles. This requires a long-term commitment to lifelong learning from those in working life in order to extend their software engineering skills. However, there is no information on how much time software developers spend on developing and maintaining their skills within a year. We have carried out an industry survey in Finland to assess, among other things, how much time software developers dedicate to professional development activities over one year. The survey had 88 respondents, all of them involved in software development within their own organization. The results show that surprisingly few participated in any lifelong learning activities or have completed professional certifications at all. This was unexpected given the importance of such education and certifications for software engineers. In this study, we reflect on the industry survey results through a discussion on the experience of organizing lifelong learning training in the field of IT sector at the University of Turku, Finland. Lifelong learning courses must be independent of time and place and be easily adaptable. Typically, the basic courses of university degree education are not directly suitable for lifelong learning students and they especially expect direct sector-specific relevance to working life in course content. The role of universities and higher education institutions in lifelong learning for software engineers should be strengthened. Universities should invest not only in the development of basic education but also in lifelong learning training and provide working people with multidisciplinary views and wide-ranging information on new topics. Learning does not stop after graduation, and therefore, more attention should be paid to this issue also during basic software engineering studies.

KEYWORDS

Lifelong learning, Software engineering, Industry survey, Professional certifications, Continuous learning implementation, Standards: 7, 8, 9, 10

INTRODUCTION

A successful software developer must possess a wide range of skills and talents. Typically, software developers are highly educated with bachelor's, master's, and/or doctoral degrees (Jazayeri, 2004); (de Rojas, 2019). Software developers often supplement their expertise with a product or topic-specific professional certifications, and earlier research has found that software developers are one of the occupational groups with a large number of professional certificates ((Cunningham, 2019); (Furnell, 2021). Well-known degrees or certificates are an advantage in IT industry public procurements as a contracting entity may require tenderers to provide a certificate or a diploma as evidence for the criteria set out in the tendering process ((Ministry of Economic Affairs and Employment, 2016).

The practical knowledge in the industrial environment is crucial for software developers due to the rapid development of the industry and technology, from which follows an increasing need for continuous lifelong education for software developers to constantly update their knowledge and skills (Rösiö, Zetterlind, Brolin, & Cannmo, 2022). Software engineering education has changed and evolved greatly in recent decades. The rapid development of technologies and ever-changing skills needs pose a challenge for education providers, such as universities, to keep up with the changing skills and competencies needed in the workplace and to provide training solutions adapted to different situations.

Adult learning has been identified as a focus topic of the European Education Area (European Commission, 2021); (Ministry of Education and Culture, 2019); (Valtioneuvosto, 2022). The aim is to respond to the competence needs arising from changes in working life. Universities play a critical role in the implementation of lifelong learning. Employed software developers should be motivated to develop and maintain their professional skills. This requires universities to develop their lifelong learning practices and find training solutions that are suitable for working adult learners, as e-learning solutions, for example, bring many opportunities for students, but also include many challenges (Kara, Erdoğdu, Kokoç, & Cagiltay, 2019).

In this paper, we examine how much time Finnish software developers spend on training in one year and how many professional certifications they hold. We also examine findings on the implementation of lifelong learning education at the university level. The engineering education curriculum at the University of Turku, Finland, follows the CDIO model. Therefore, the development and success of lifelong learning training in the IT sector could be reinforced by using and strengthening CDIO objectives as part of lifelong learning curriculum and course development.

PREVIOUS WORK

Software developers are in high demand with technical skills including problem-solving and innovation. There is a shortage of skilled and trained software developers and more would be needed to meet the needs of working life. According to a report by the (Ministry of Economic affairs and Employment, 2020), software companies in Finland need around 5 000-6 000 skilled workers per year. Software workers are required to have up-to-date technical knowledge of, for example, specific programming languages, cybersecurity and privacy, and development frameworks and practices. In this sector, skills are ageing rapidly due to the fast pace of technological development (Ministry of Economic affairs and Employment, 2020). This place demands on the teaching and development of software engineering education. The practical competence of the software engineering profession needs to be complemented by the skills of professionalism, group dynamics, and communication (Garousi, Giray, Tuzun, Catal, & Felderer, 2020); (Rösiö et al., 2022); (Klaassen & de Bruin, 2022).

As the IT industry is rapidly changing and evolving with technological developments, software developers must be committed to lifelong learning, where their skills and their up-to-dateness must be verified by a third party (e.g. customer, recruitment situation). This situation is particularly evident in public procurement, where the degrees and professional certifications of the supplier's employees play an important role as part of the selection criteria (see: a certificate as proof; (Ministry of Economic affairs and Employment, 2020)). For this reason, software engineering education must be able to develop and provide the skills and competences necessary for working life. Previous research is twofold. Some point out that the current training does not meet the expectations of industry (Garousi et al., 2020);(Tuzun, Erdogmus, & Ozbilgin, 2018); (Aasheim, Williams, & Butler, 2009);(Lethbridge, 2000). However, previous research also shows that students learn the knowledge and skills needed during their IT studies, and thus the teaching of software engineering would not be badly outdated (Jakupovic & Carstensen, 2017).

Adult learning has been identified as a focus topic of the European Education Area for the period 2021-2030 (European Commission, 2021). In Finland the reform of continuous learning focuses on the development of the competence of working-age people (Ministry of Education and Culture, 2019). The aim of this reform is to respond to the competence needs arising from changes in working life. This places expectations on higher education institutions in terms of continuous learning arrangements.

The terms competence, knowledge and skill often come up when defining training and education expectations. In this paper, the terms are defined according to the EN 16234-1:2019 e-Competence Framework (e-CF): Competence: demonstrated ability to apply knowledge, skills and attitudes for achieving observable results; Knowledge: body of facts which can be applied in a field of work or study (know what to do), and Skill: ability to carry out managerial or technical tasks, and they may be cognitive or practical (know how to do it). (European Committee for Standardization, 2019)

It is clear that the structure of the curricula and courses for lifelong learning requires systematic development and innovation to find teaching methods and solutions suitable for various situations. In the early stages, lifelong learning courses and curricula may start out as individual courses, or be a collection of good courses, or a composite set of existing courses that may not be linked to other courses or even crucial content is missing (Granholm, Haajanen, Ketola, & Norström, 2021). Running continuous learning courses also involves various challenges, such as, challenges related to internal, external, and program-related factors (Kara et al., 2019). In this context, the use of the CDIO objectives can bring benefits and promote industry links to lifelong learning curricula, courses, and teaching methods. The CDIO standards (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014) guide course developers in this task, and several standards explicitly refer to industrial relevance and characteristics that need to be acquired during engineering education (Rösiö et al., 2022);(Klaassen & de Bruin, 2022).

RESEARCH APPROACH AND RESULTS

In this chapter, we summarize the research approach and describe how the industry survey was designed and carried out in Finland. It should be noted that the survey was designed to answer several research questions related to quality, security, and privacy practices than those discussed in this paper. However, the survey was specifically designed to find answers in terms of time spent on training. In this chapter, we will also discuss the results of the survey related to the development of the competence of IT professionals.

Questionnaire and industry survey implementation

The industry survey was targeted at Finnish software engineers/developers, and others directly involved in software development processes. Two approaches were used to collect responses. First, the research was conducted as an invitation-based online survey. The survey was communicated through the University of Turku Alumni Monthly letter and in the communications and events of FISMA (Finnish Software Measurement Association) and Sytyke Ry. The second method used was direct email invitations. The e-mail addresses were collected manually from the website of the Finnish Software Entrepreneurs Association. For ethical and privacy reasons, only software developers of those companies that clearly stated and indicated email addresses or the format of the email address were sought. The survey was open from mid-October 2019 to the end of February 2020. Two reminders were sent: at the beginning of November and at the end of November. A total of 88 valid responses were received. The exact response rate cannot be calculated as the survey had a public web link, but the response rate can be interpreted as low, which is typical for similar kind of online surveys. In this study, approx. 71 % of the responses were received through the public web link to the survey. The public web link method was the most productive compared to direct invitations.

Based on the survey data, 92 % respondents had a degree from a higher education institution: bachelor (32 %), master (53 %) and doctoral/licentiate (7 %), and 8 % had either upper secondary school or ongoing studies. The respondents were highly experienced: less than 1-year: 3 %, 1-5 years: 22 %, 6-10 years: 16 %, 11-15 years: 13 %, and more than 16 years of IT work experience: 46 %. Respondents work on the following kinds of topics: development, design, architecture, testing, project management, quality management, security management and privacy management. About 10 % work in organizations with less than 10 employees, 22 % in 10-50 employees, 13 % in 51-100 employees, 9 % in 101-250 employees and about 44 % in organizations with more than 250 employees. The range presumably reflects the current structure of Finnish software companies and is close to other similar studies. These results show that the survey was able to reach especially those who have been working in the IT industry for a long time. This was probably made possible by the communication carried out by FiSMA ry (Finnish Software Measurement Association) and Sytyke ry (Sytyke ry brings together Finnish software development professionals and is the largest nationwide theme association of the TIVIA, Association of Information and Communication Technology Professionals).

Industry survey results: IT professionals' time spent on training and the number of professional certificates

Based on the survey results, we can identify that IT professionals spend surprisingly little time developing their skills over a one-year time period. In fact, 14 % of respondents report that they have not spent any time on skills development during the year. On average, 46 % did not attended training during the year, 29 % 1-3 days, 9 % 4-10 days, 6 % 2-4 weeks and 6 % more than 4 weeks. When looking at the entire group of 88 respondents (Figure 1). Most time has been spent studying security and privacy issues. And even for this, the time spent has mainly been a maximum of 1-3 days. At the time of the survey's implementation, GDPR issues were particularly topical and urgent (In Finland, the GDPR entered into force on 1.1.2019). For this

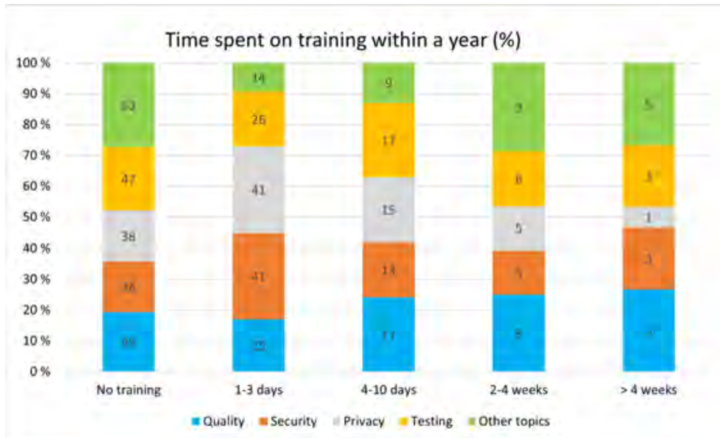

Figure 1. Time spent by IT professionals on training within a year

reason, the time spent studying privacy issues is also remarkably low. In addition, it should be noted that the respondents have separately given the training time spent on a specific topic (e.g. quality topics: 1-3 days, technical/other topics: 1-3 days, etc.). Therefore, some have reported more training time per year, while others may have chosen only one topic or none. This further demonstrates the IT professionals' limited time allocated to training.

When analyzing the training times, we can identify that the work experience of IT professionals does not have a noticeable positive correlation with the time spent on training. In a similar way, the size of the company also does not contain a positive correlation with the time spent on training. In this study, searching for information on the Internet is not defined as participation in training and competence development, and thus, training is at least participation in a slightly more formal training event.

When looking at the number of professional certificates, approx. 67 % do not have any professional certificates. This result is surprisingly low, given the importance of degrees and professional certifications as part of procurement tenders in the IT sector. The results show that work experience has a strong negative correlation with the "no certificate" result (-0.460). This means that IT professionals as a whole do not have many professional qualifications, regardless of their educational background, work experience or the size of their company. However, work experience has a significant positive correlation with technology certification (0.283), project management certification (0.330), and the rest of the certificates specified in the section "Other" (0.278, such as SAFe, ITIL, COBIT, TOGAF certificates). The results showed that the more experience, the more likely an IT professional was to have a professional certificate. And having one professional certificate increases the likelihood. As can be seen in Figure 2, the number of certificates starts to increase for IT professionals with 11-15 years of work experience, and especially for IT professionals with more than 16 years of work experience.

When examining the size of the company, it was found that professional certifications have been completed especially in large companies. (Figure 2). This indicates that large companies have an interest in investing in workers' professional certifications, as qualifications and certifications play an important role in tendering situations, and large companies may have better financial conditions to pay for employees' certification training.

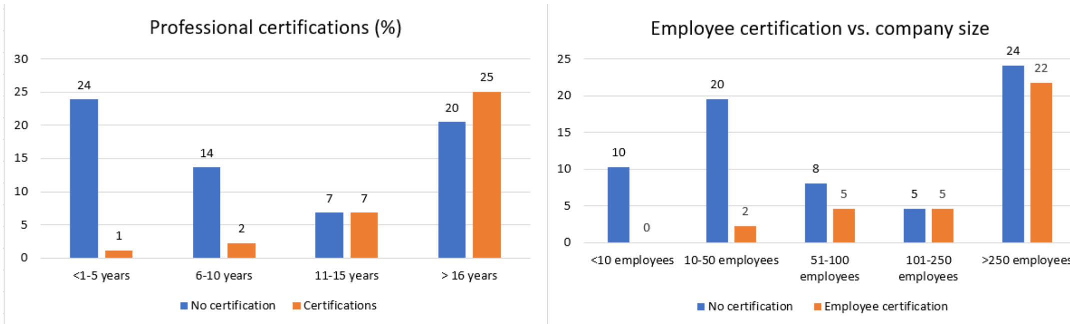

Figure 2. Professional certifications per IT professionals' work experience (%) and per company size (%)

Lessons learned from organizing continuous learning at the department of Computing

Over the past three years, the Department of Computing at the University of Turku has offered and implemented several training modules for continuous learning in the IT sector. These include projects, such as: ICT-Sote (30 ECTS module of several IT courses), SOTE-Akatemia (courses, suc as, Digitalisation in healthcare and social welfare services; Information and Cybersecurity courses), FITech university network (various IT courses across seven universities), LEADBEHA (Information and Cybersecurity course), and also various Open University courses. These are the observations and experiences of several teachers who have been in charge of continuous learning courses, which have been discussed together in the context of course implementation and development activities.

General topics. *Communication and course marketing*: Promoting and marketing courses is time-consuming. The most effective marketing approach is through employers. Marketing is easier if there is money available for marketing. *Administrative aspects*: Time must be reserved for collecting, maintaining, reporting to the funder, making user IDs and records of students and their studies. *Low completion rates*: Free courses collect enrolments, but the completion rates are low. Free courses are easy to drop out of because there is no financial loss for students. *Employee related challenges*: Successful course implementation should not be built on several part-time employees. Participating employees must be motivated to implement continuous learning courses. Otherwise they will slow down or, at worst, hinder the implementation of the course. *No possibility to get a recognised certificate after the completion*: Universities do not usually give out certificates or diplomas after the course. Instead, universities can give course credits and it is possible to acquire a transcript of academic records, which are not as well recognized in the IT sector as professional certificates. This raises the question of why students should choose a course for which there is no possibility of obtaining a recognized certificate or diploma as proof of course/content completion.

Curricula and Courses. *Students prefer time- and place-independent courses*. It should be noted that students can participate in lifelong learning throughout the country. For this reason, remote participation should be made possible, even if on-site teaching is available. Course materials should be provided as ready-made lecture videos, and materials and assignments directly available in the course area. That way the student can complete the course at a time and at a pace convenient for themselves. In addition, we have observed that an extension to the completion of courses is often requested or the students continue the course with the next implementation instance. Also, taking exams may be an obstacle for some students, and therefore do not participate in the course if it includes exams. *Building course content*. Building course content requires a lot of content and contextual knowledge in the field. It is necessary to have a clear idea of the needs of students and, on the basis of these, if necessary, make changes to the content of the courses. *The courses require a lot of customization*. The courses offered to the university's degree students are not directly suitable for students of continuous learning. Students of continuous learning want sub-specific topics that benefit them quickly and directly instead of general knowledge. *The importance of relevance to working life*. The requirement for relevance to working life takes on an even greater role. For this reason, a clear working-life connection must be built into the courses. And one way is, for example, to include several guest lecturers from various workplaces to bring in sub-specific competencies, e.g. information security, law, data protection, procurement process, and robotics. Success requires a good network of experts and partners in the field from the course creators. *Communication during the course*. Communication is very time-consuming. A separate resource should be nominated for this role, who will take care of motivating students, communicating, and contacting students personally. This is a kind of "supertutor" who can teach courses, instruct, communicate and supports students' progress, etc. Through communication and support activities, it is possible to improve the completion of the courses by maintaining connection with the students. *Learning verification*. Students' coursework must meet the university's course requirements for it to be eligible to be included in a degree.

Student related. *Lack of employer's support*: The motivation to complete the courses decreases if the employer does not support studying during working hours. *Time management challenges*: Quite many have challenges combining work and training or combining training and family or social life. *Lack of technical skills*: Problems with technical things, such as, cannot open lecture videos, and changing passwords. *Inability to understand course materials*. Typically, students participate in continuous learning courses with very different basic education and competence backgrounds. Especially if the student's basic education is from another field than IT, the concepts and language of the IT field can become a challenge.

From teachers' perspective, students who complete life-long courses are typically motivated and active. Students' work experience helps them to reflect topics in more depth. This reflection is particularly interesting for teachers because it allows them to see and hear examples of work-life applications and situations related to the subject being taught.

DISCUSSION

Often participants on a life-long learning course are already established professionals looking to deepen and gain multi-professional insights and expertise. In our experience, courses for life-long learning are not a by-product of regular curriculum teaching, but rather require their own dedicated group for designing, implementing, and evaluating learning contents and outcomes. Life-long learning courses are more often arranged in non-traditional ways. Rigid on-site classroom teaching is not feasible for most working professionals. Application of flexible and new teaching methods, technologies, and practices is thus more likely utilized in life-long learning courses. In addition, due to the coupling with work life, new course content developed for such courses can be integrated to regular courses.

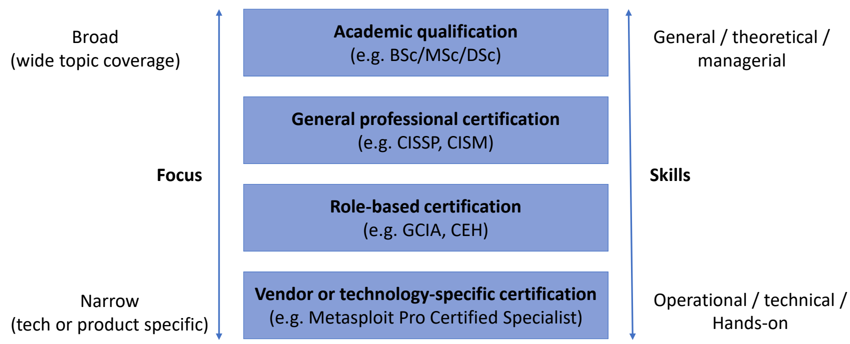

Figure 3. Focus and skill types for cybersecurity certifications. Adapted from (Furnell, 2004).

The unique potential for multidisciplinary view of universities should be more readily utilized to provide students with new insights into their chosen field of profession. One potential approach would be to use life-long learning courses to give students from industry an opportunity to learn the latest research directions and topics from academia. Here the research-based education that universities are responsible for can bring more added value to industry students. The focus should not only shift from teaching at university to maintaining and developing skills after the transition to work. The CDIO community and standards should also play a role in the process of continuing engineering education. The real learning in software engineering starts after graduation. The aim should be a continuum of continuous learning of technical subjects throughout a career. This is also reflected in the CDIO standards, which clearly outline a path for both creating suitable educational content and methods for life-long learning courses for software professionals. At the same time, the competence of educators must be enhanced. Educating postgraduate software engineering professionals requires a different set of competences compared to degree students. Industry co-operation and experience, demonstrated by for example professional certifications is one solution.

The importance of life-long learning might not be recognized or even required in companies in the same way as for degree students. The reason may be the lesser attention and importance of continuous education and its importance as a form on competence development. For example, in cybersecurity, established professional certifications are usually very highly regarded and are understood as proof of competence and skill in the area. Figure 3 shows the different focus and skill ranges for cybersecurity certifications. Academic qualifications are clearly in the domain of universities. In the other end of the spectrum are vendor and technology-specific certifications (e.g. Cisco product certifications provided by Cisco Systems, Inc.). In the middle are generic and role-specific certifications, where new openings for life-long learning can be made for universities.

One potential way of bringing certifications available to university students is to collaborate with technology vendors. As an example, at University of Turku we have successfully done this in the past (see e.g. (Hakkala & Virtanen, 2012)). Unfortunately, university-industry cooperation is also vulnerable to shifts in company policy or external circumstances, such as mergers and acquisitions. A better solution would be for universities to be in control of the certification. The landscape of professional certifications is also varied and there is a plethora of certifications to choose from. As observed by (Furnell, 2021), there are multiple certifications in the same areas of cybersecurity that are not interchangeable, and that there is no clear way to reliably choose the correct certification for a role or position, making it difficult to navigate the potential pitfalls of unsuitable certifications. This phenomenon is not limited only to cybersecurity but can be generalized to other fields as well. The role of universities could be to provide a clear continuum from academic qualification towards general and role-based certifications.

Given the reputation and societal role of universities as the givers of highest education by law, why have universities not yet developed a system for granting certifications for life-long learning activities? The way Finnish universities only give ECTS is clearly not a viable solution in industry. We recognise that the situation may be different at universities in other countries, and in some countries there are certificates called "graduate certificates". These are partial bachelor's or master's degrees, but not specifically designed for professionals already in industry. Therefore, it is questionable whether these certificates granted by universities are really globally recognised in the same way as, for example, the CISSP certificate. Our idea is that the content of continuing education can actually be something quite different from what is taught to degree students, i.e. a real professional certificate that supports the maintenance and development of skills and competences. What is produced for degree students is not adequate for this purpose. A large proportion of software developers already know all this, as they have work experience and a BSc/MSc or even a DSc degree from an IT field.

Professional certificates are significantly more valued in IT industry, and universities should leverage their institutional strengths to create such respected professional certifications for IT professionals. It is understandably difficult to establish a new professional certification and to gain sufficient recognition for it to be considered proof of competence for the certificate holder, but universities are in a good position to do this. Life-long learning degrees and programs in economics and commerce (e.g. MBA and management courses) are proof that universities can provide credible study packages in the open market. This capability should also be leveraged in other fields of study.

CONCLUSION

The purpose with the paper was to find out how much time software developers use on competence development and training within a year, and how many professional certificates they have. Surprisingly, software developers spend relatively little time on training and skills maintenance during the year, regardless of work experience and company size. Contrary to expectations, software developers did not hold many certifications. The number of certifications only started to increase after more than 10 years of work experience and the larger the company they work for. This indicates that after graduating from higher education institutions, software developers do not commit to long-term lifelong learning. This mindset of lifelong learning should be instilled in students already during their graduate studies. The implementation of lifelong training should be invested in the same way as degree education. For this reason, it should not be done alongside other work but requires systematic planning, funding, and dedicated human resources. In addition, universities should offer real options as producers of lifelong learning and look at the possibility of offering students not just credits, but also recognized certificates that have value in the industry. The implementation of lifelong learning can be developed and strengthened through CDIO standards related to (7) Integrated Learning Experiences and (8) Active learning.

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BIOGRAPHICAL INFORMATION

Anne-Maarit Majanoja is a University Teacher (PhD) in software engineering at the Department of Computing, University of Turku, Finland. Majanoja has more than a decade of work experience in the industry and her work experience has equipped her with an in-depth knowledge of global IT development and services, quality management, leadership, and logistics and supply chain environments. Majanoja has also worked for several years in the development and implementation of lifelong learning courses and content at the University of Turku. Her current research interests include: quality management, process development, global IT outsourcing, leadership and change management, and IT education and lifelong learning.

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Seppo Virtanen is a Professor in Cyber Security Engineering and Vice Head of Department of Computing, the University of Turku, Finland. He is a Senior Member of the IEEE. He has taught more than 70 instances of 23 different university courses to engineering students as principal instructor. His current research interests are on cyber security in smart environments, secure network and communication technology and security technologies for IoT.

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HYBRID EDUCATION – A CRITICAL REVIEW INTO CHALLENGES AND OPPORTUNITIES

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ABSTRACT

Hybrid education is a complex combination of simultaneous face-to-face and online teaching. This model of teaching comes with a wide range of benefits, primarily being able to offer the same content to a wider audience. Hybrid education became an effective form of teaching during the COVID-19 pandemic. In these post pandemic years, the benefit of hybrid education can still be utilized, allowing for improved flexibility in teaching schedules, engaging students in interactive learning, bringing online students closer to the teacher and face-to-face students, and offering education to students who could not otherwise participate. However, with all the benefits of hybrid education, there are some significant challenges which restrict the implementation or hinder the full potential of hybrid education. Some key challenges are student engagement from the online students with the teacher as well as with other students, technological requirements, physical classroom set-up, education of the teachers, and time investment in re-structuring courses. In this article, we review the challenges of hybrid education, strategies to address these challenges focusing on implementation and effectiveness, as well as evaluating student feedback from students at Jönköping University that have been a part of hybrid education.

KEYWORDS

Hybrid education, Student engagement, CDIO Standards: 8, 10

INTRODUCTION

Hybrid education combines traditional face-to-face instruction with online learning, offering a unique approach to teaching and learning that has numerous potential benefits. The objective with the study was to evaluate the effectiveness of hybrid education in some of the courses that have adopted this educational approach, to examine the pros and cons encountered by students and teachers, and to observe the impact in a real-world setting. At the School of Engineering (JTH) at Jönköping University (JU), the decision was taken to conduct a study on hybrid education due to its increasing popularity in the educational landscape.

The students' perspective on hybrid education was collected through an online survey while the teachers' perspective was collected through semi-structured interviews. The study and its results have provided an improved insight into understanding hybrid education, its advantages, and its drawbacks. The applied research methods, the questions posed, and the obtained results are presented further on, but first the theoretical background of hybrid education with its challenges and opportunities, and the results from some previous studies in the same field, are presented.

Hybrid education – theoretical background

Amidst the pandemic, universities have adapted by finding new ways to teach and progress with courses as traditional face-to-face teaching became restricted. Alongside this forced shift, the rapid development of technology has been instrumental in the adaptation of hybrid education, as it was already being used to a degree before the COVID-19 outbreak. The pandemic, however, has caused a significant increase in the implementation of hybrid education. Hybrid education is one of the newest educational methods, which allows some students to attend classes in person and others to join online simultaneously (Raes, 2022). Hybrid education is used when you have two cohorts of students, at the same time, that cannot be together in the same space due to time, physical or other constraints. Hybrid education often has different definitions, however for this study, the authors refer to hybrid education as a combination of face-to-face and online synchronous teaching that creates a cohesive learning experience.

The development of hybrid education has caused the traditional pedagogical methods to evolve, as the customary resources, functions, and classroom settings are being broadened, re-evaluated, and renamed. Hybrid education is emerging as an educational option that allows access to people who, for various reasons, are unable to access more traditional educational approaches, such as face-to-face learning. For this to be successful, a collaborative atmosphere needs to be established, with equal communication for all parties involved (Gao et al., 2020). Iivari et al. (2020) posed that the concept of learning will go through a radical transformation, taking us to where we should have been from the start. This implies that teaching cannot be restricted to the classroom (Ayub et al., 2022) and could be extended through forms of online education to have a positive impact on the students' learning.

The research in the literature does not always present a clear definition of hybrid teaching, which includes not clearly distinguishing it from other forms of lesson delivery (such as blended learning) or describe how this type of teaching is conducted in the classroom setting, especially after the COVID-19 pandemic (Ulla & Perales, 2022). However, there is still a strong support for hybrid education, and it can be seen as one of the answers to 21st-century education (Singh et al. 2021). The evolution of teaching techniques has resulted in the emergence of hybrid education. Nowadays, the concept of hybrid education is one of the most talked about topics when it comes to forms of online education; it involves a considerable amount of course material and interactions between teachers and students that take place virtually and physically simultaneously. It encompasses various forms of communication and collaboration, as demonstrated in Figure 1, for creating an effective learning environment.

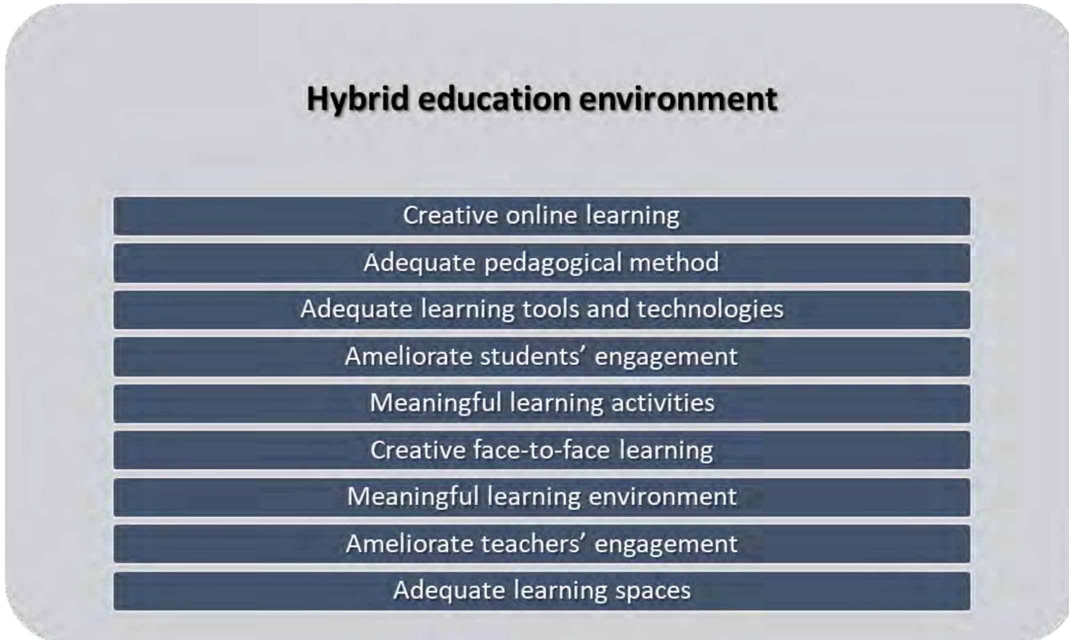

Figure 1. A hybrid education environment.

Hybrid education – challenges and opportunities

Effective learning requires that higher education institutions strategize ways to enable individuals to participate in enriching learning activities. In our increasingly international and interconnected world, it is becoming harder for people to be physically present in one place for a long time (Slavensky, 2019). Furthermore, the student demographic is altering, and individuals are finding it difficult to balance study, work, and family life. To solve this problem, education must become less dependent on location and timing and allow more flexibility within the learning program (Lakhal et al., 2017). Additionally, there is a need to collaborate beyond the borders of institutions, incorporate knowledge from external organizations, and deal with rising numbers of enrolment and diminishing institutional budgets (Stupnisky & Butz, 2016). One way of dealing with these issues is to introduce hybrid education as a pedagogical tool and technological platform where the synchronous modality is one alternative.

Although hybrid education can provide a wide range of benefits, such as cost savings, increased flexibility, and access to educational resources, it also presents some potential challenges. The concept of hybrid education is not simply a combination of online and face-to-face instruction. Rather, it focuses on optimizing the achievement of the intended learning outcomes by applying the "right" learning technologies to match the "right" pedagogical approach to the "right" student at the "right" moment in time (Graham, 2005).

Hence, teachers must adjust their pedagogical approaches to accommodate the new technologies in synchronous hybrid education environments (Cain, 2015; Ramsey et al., 2016). This type of education requires different teaching methods and engaging learning activities (Bower et al., 2015; Weitze, 2015; Weitze et al., 2013). When considering student engagement (and disengagement), all dimensions should be contemplated by the teacher, that is, behavioral - follow rules & complete tasks, cognitive – adopt an active process of learning, emotional - reaction to learning, social - invest in a collegiate experience and collaborative - create relationships (Bergdahl, 2022; Redmond et al., 2018). Teachers should be aware of these dimensions and prepare different activities within the hybrid learning space to try to deal with these.

Teachers must be able to maintain comparable education standards while adapting to the new environment (Grant & Cheon, 2007; Lightner & Lightner-Laws, 2016). For teachers to successfully use the technology and create high quality teaching, they must have the opportunity to practice and assess the results based on evidence (Grant & Cheon, 2007; Weitze et al., 2013). Consequently, CDIO standard 10 needs to be addressed as it focuses on teachers' competence development in relation to possibly new and different teaching methods.

Teachers must also take on extra coordination for hybrid education environments (Ørngreen et al., 2015). During instruction, teachers must pay attention to both the remote and the face-to-face students, as well as the technological platform. This requires a heavy mental load, known as hyper-zoom or hyper-focus (Bower et al., 2015; Zydney et al., 2019; Ørngreen et al., 2015). The goal of hybrid education is to provide a similar learning experience for both remote and face-to-face students (Szeto, 2014; Zydney et al., 2019). To do so, teachers must design and implement pedagogical strategies and technological systems that will create a sense of co-presence (Bower et al., 2015; Cain et al., 2016). Care should be taken, however, to ensure that teaching strategies, such as a slower pace with more repetition, do not compromise the learning of face-to-face students (Bower et al., 2015; Szeto, 2014; Szeto, 2015).

Olt (2018) studied the phenomenon of hybrid education from the perspective of the remote participant and found that the negative experience could be explained by the concept of 'ambiguity' in terms of group membership, technology functionality, and location. Huang et al. (2017) also noted that the remote students felt excluded from the main class due to physical separation and technical difficulties without adequate support. On the other hand, the face-to-face students felt neglected when the teacher devoted time to resolving these issues. Activating and engaging the remote students at the same level as face-to-face students is difficult in hybrid education. Weitze (2015) found that remote students learned less, were more passive, and seemed to be watching TV rather than attending the lesson. This is attributed to many teachers using monologue-based teaching strategies, which are not appropriate for this setting. A way to get around this problem is to use online student-driven active learning modules that ensure that all students (and not only the face-to-face students) are active and engaged (Ahlin, 2021).

Weitze et al. (2013) found that remote students find it difficult to make the teacher aware that they want to answer a question, leading to frustration and disengagement. The hybrid education environment requires more self-discipline from remote students (Wiles & Ball, 2013), as the teacher is not physically present to monitor their engagement. To address this, teachers must invite remote students to participate in class activities (Weitze et al., 2013). One way could be to apply quizzes and polls to monitor student engagement (Bower et al., 2015; Pick & Cole, 2021; Raes et al., 2020; Sebae et al., 2019). They benefit both the teacher and the student. Teachers can use the results to adjust their teaching and identify gaps in student understanding (Bower et al., 2015; Lightner & Lightner-Laws, 2016). For the students, it is a way to give feedback to the teacher and let them know when a student is struggling with a topic (Lightner & Lightner-Laws, 2016).

Remote learners also feel a sense of distance from their institution, so there must be a way to connect remote students, teachers, and face-to-face classmates (Ramsey et al., 2016). To address this the audience response system (ARS) could be used. It has shown good results regarding student satisfaction, learning outcomes, engagement, and levels of confidence

(Assad et al., 2022). Every 15-20 minutes during a lecture, both face-to-face students and remote students alike will be exposed to a short practice and exercise related to the topic of the lecture followed by thinking-aloud pair problem solving (Brent & Felder, 2012), ending with clarifications and class discussions. This active classroom approach is in line with CDIO standard 8 that stresses the importance of “teaching and learning based on active experiential learning methods”.

FINDINGS AND DISCUSSION

In order to better understand how hybrid education is both taught by teachers and received by students, interviews with teachers and a survey which was sent out to students at JTH who had taken part in hybrid education were used. The survey was limited to 10 questions as shorter surveys are found to improve the response rate. The survey was designed to address the challenges and opportunities as identified in the previous sections, and the interviews were an open dialogue discussion with some pre-planned questions to get the teachers’ perspective. It is pertinent to point out that the majority of the courses involved in these results were a necessity during the COVID-19 pandemic.

The survey showed that the majority of the students adapted positively to hybrid education, with an average of 5.3/7 when asked to rank how they would describe their experience in hybrid education from 1 (negative) to 7 (positive). The method of hybrid education that the students took part in was primarily lectures/seminars at 92.3%, with 23% of students also taking part in laboratory or other forms of activities. This is interesting to show that hybrid education does not need to be limited to classroom lectures but can also be adapted to other forms of teaching that typically require more interaction. The students showed that there was an even split between online and in-class students, and when asked if they felt a greater (or lower) motivation and engagement in their personal learning approach because of hybrid education, 35.7% of the students responded with a higher impact, 42.9% no impact while 21.4% mentioned they had lowered their motivation. This could be expected as the challenges for student engagement have been well documented with online students, however, it is interesting to note that the primary source of students that mentioned it had lowered their motivation were on-site students. From the students’ open comment responses, this is primarily linked to the teacher requiring him/her to spend more time dealing with online students or technical issues instead of the typical focus the teacher would have in class.

The students were asked questions around the benefits of hybrid education and what could be improved to increase their positive experiences, and the common key words are presented in Table 1. The most observed response for the benefits with hybrid education was the flexibility that it offers. This allowed several students who would otherwise miss the lecture to attend, with the most common reason being sickness or travel time/difficulty. The second most common response was that they had the opportunity to re-watch the recorded lecture as most of the lectures are now also recorded due to the online component. This was even seen with the ways to improve the learning experience where the students who did not receive a recording after the lecture commented that this was missing. This is therefore a simple yet useful tool for the students in the learning process, however it could be seen as a method for students to easily miss the live lecture and instead watch the video. This is not necessarily an issue for typical lectures, however if there are discussions throughout the teaching period, the students will miss this learning opportunity and the teacher may have fewer students for the activities than planned. The students also identified that the quality of a video is important in order to improve the experience.

Table 1. Common student feedback on hybrid education.

What do you see as the benefits of hybrid education?	What could have been improved to increase your positive experiences?
• Flexibility – Sick, travel • Re-watch lectures that are recorded • More students are able to attend	• Better video quality • Keep online students engaged • Always record the lectures • Delay between online and on-site student/presenters

Finally, the students were asked if they would take part in hybrid education again, with 85.7% responding that they would with positive comments of the schools' approach to move towards hybrid education. From the students' perspective, it appeared that the students adapted quickly and efficiently to hybrid education, and really appreciated the flexibility that it offers. Further investigations are being conducted into the student course satisfaction surveys to identify the long-term trends of courses switching between on-site and hybrid courses. This will ideally give further insights into the impact of hybrid education.

While it is extremely important to identify the effect of hybrid education on students, the impact that switching to hybrid education has on teachers is often discussed as a challenge caused by an increased workload. The teachers identified that they did not greatly change their course content, and the adaptation to hybrid education was the simultaneous filming and streaming to the online students, and that this form of teaching was chosen out of necessity or request as opposed to personal choice. The teachers that were interviewed did not attempt cross-engagement between online and on-site students during problem-based learning which reduced some of the challenges typically identified within hybrid education. While the teachers did not note a significant increase in the preparation, they found that it was a learning curve to ensure that the lectures run smoothly in practice, and there was an increase in energy during the class to ensure that both online and on-site students received the attention required to not diminish the learning experience that was noted from the students' perspective. It is a reasonable assumption that hybrid education could be improved if there was an assistant present to help with the recording and the online students so that the teacher can focus on teaching, knowing that both groups are well attended. This would improve the online experience, and not break up the on-site experience. However, this does come at an additional cost and time commitment of having an extra person in the classroom for all teaching sessions. It was also interesting to hear that most teachers would prefer not to use hybrid education unless they see that it gives students, who otherwise would not be able to attend, a chance to attend, for example students with visa issues who are unable to enter the country.

CONCLUSIONS

Hybrid education has emerged as a useful method of teaching, which has advanced due to various technologies and the requirement for alterative teaching methods during the COVID-19 pandemic. Several challenges and opportunities have been well documented within literature regarding hybrid education.

Surveys and interviews with students and teachers were implemented within this study to identify how hybrid education is taught and received by the students. It was found that the experience was positively received by the students at JTH, with the majority finding the benefit of flexibility and being able to re-watch the lessons when also recorded contributing factors to this experience. The students identified a poor video quality and interruptions as key areas for improvement in moving forward with hybrid education. The response of students showing that the majority would enroll in a course with hybrid education highlights that this is largely a positive experience and a teaching method that should be further investigated and practiced.

Further studies into the student satisfaction surveys from courses which have swapped between on-site and hybrid education are currently underway to supplement this study with longer term trends of engineering courses at JTH.

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ENGINEERING OR COMPUTER SCIENCE, WHAT IS THE DEAL?

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ABSTRACT

There is still a gender bias in the Science, Technology, Engineering and Mathematics (STEM) sector. The progress towards gender balance has been very slow. The situation is not good enough in engineering education and is even worse in computer science. Many studies have been carried out and many projects and efforts have been made to accelerate the development over the years. Influencing factors are many when young people are deciding what subject to study at university and the trend is still for males to go for STEM studies and females to aim for health sciences and social sciences. This paper presents findings from a study on gender differences in engineering and computer science by questioning female students at the university level to learn what could be the reasons for more girls preferring STEM study and how they are doing in their study. This topic touches on CDIO Standards 1 (program philosophy), 7 and 8 (new methods of teaching and learning).

KEYWORDS

STEM, Gender differences in education, Choice of studies, CDIO Standards: 1, 7, 8

INTRODUCTION

It is problematic, not only for girls and women but for the whole society that females are underrepresented in Science, Technology, Engineering and Mathematics (STEMs). The situation affects the STEM industry and education as well as female's personal life, the situation is simply a drawback for society. STEM industry and education will need to be inclusive for future development. The situation is well documented but the many projects that have been carried out have not changed the situation, although they may have moved the trend toward a better gender balance. Anyhow, the number of women graduating in computer science in the USA has been decreasing from 37% in 1984 to 18% in 2018 (AAUW, 2018). In the EU the gender gap in STEM is particularly wide in IT and in 2021, women were 32.8% of the working force in high-tech manufacturing and knowledge-intensive high-tech services in Europe (Catalyst, 2022).

LITTERATURE REVIEW

In the UNESCO report, *To be smart, the digital revolution will need to be inclusive*, by Bello et al. (2021), it is emphasised that women are at risk to miss out on jobs of the future. The Fourth industry revolution (4IR), or Industry 4.0, is changing the job market as many low-skills jobs will be automated, which calls for a higher level of education and skills and it has been anticipated that for one job gain through Industry.4.0, women will lose five jobs but men three (UNESCO, 2018). There is a shortage of skills in STEM which gives women the opportunity to step in and fill the gap but that calls for them to gain the "right" skills in e.g. artificial intelligence, computer science and engineering (Bello et.al., 2021). STEM academic degrees give access to many well-paying jobs that are fast-developing today (Cedefop, 2016; European Union, 2016; European Commission, 2017; World Economic Forum, 2021) but women are not grabbing the opportunity and men are still dominating the field. Even though women have a STEM education they may not be working in the field (Van Veelen, Derks & Endedijk, 2019). A report by Singh et al. (2013) indicates that around 30% of women who enter engineering ultimately leave the profession. And, if women choose engineering they are more interested in health-related subjects within engineering (Funke, Berges & Hubwieser, 2016; Lin, Ghaddar & Hurst, 2021) as a research from 2021 shows where female students choose biomedical engineering and male students mechatronics engineering (Matthiasdottir & Audunsson (2022).

The driving fields in Industry 4.0 is digital information technology, computing, physics, mathematics and engineering, the very fields wherein women remain a minority. This situation has been analysed and discussed in the literature over the years (Ashcraft, Eger, & Friend, 2012; Stoeger et al. 2013; Kolmos, Mejlgaard, Haase, & Holgaard, 2013; Liben & Coyle, 2014; Cheryan, Master, & Meltzoff, 2015; Matthiasdottir & Palsdottir, 2016; Funke, Berges, & Hubwieser, 2016; Matthiasdottir, 2018). Among the conclusions in Bello, Blowers, Schneegans & Straza's (2021) report is "This trend is all the more problematic in that there is a skills shortage in many of these very fields, such as in artificial intelligence. This trend suggests that progress towards righting the gender imbalance could be compromised, unless strenuous efforts are made at the government, academic and corporate levels not only to attract girls and women to these fields but, above all, to retain them" (p. 25).

It is sometimes difficult for a young person to decide what to study. In the YouScience *Post Graduation Readiness Report (*2022) it is stated that "75% of high school graduates are not ready to make college and career decisions" (p. 1). What motivates and inspires students when they decide may be different between different persons and the process of concluding what to select can be long for many. It seems to be difficult to recognize what determines students' choices of education. It may be a complex process and the roots can be as deep as in early childhood (Van Tuijl & van der Molen, 2016). In the YouScience report, *Career Insights: Women, STEM, and the Talent Shortage* (2022), it is stated that there is a gap between what high school female students can do, their aptitude, and their interest in, e.g. they have "more than 10x the aptitude for careers in architecture and engineering than they do interest" (p. 3).

Van den Hurk, Meelissen & van Langen's (2019) review of empirical studies lead them to categorise factors related to gender differences in STEM education into three levels: environmental factors, factors at the school level and factors at the student level. Built on their research they put forward the following model in figure 1.

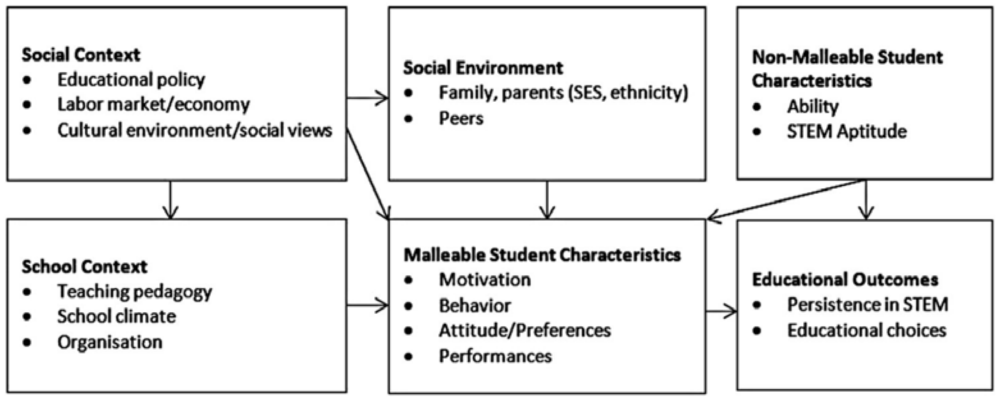

Figure 1. Model for academic choices and persistence in STEM education (Van den Hurk, Meelissen & van Langen, 2019, p. 155).

Alam (2022) looked into academic research over the last three decades and comes up with six explanations for why women are not going into STEM: (a) preconceptions and biases based on gender, (b) field-specific ability beliefs, (c) lifestyle values or work-family balance preferences, (d) professional inclinations or desires, (e) comparative cerebral capabilities, and (f) cognitive aptitude (p. 1).

Matthiasdottir (2018) shows that the genders give different reasons for choosing engineering studies. Females reported more interest in math and science and a success in those subject in upper secondary school and females were older than males when they decided what subject to study. Amelink and Meszaros (2011) emphasise the importance of faculty recognising that female students value respectful interaction and encouragement a lot.

Research have looked into more influencing factors, e.g., competitiveness (Buser et al., 2014), peer influence (Brenøe & Zolitz, 2018; Andersen, & Hjortskov, 2022), grade performance (Stinebrickner & Stinebrickner, 2011), wage gap (Redmond & McGuinness, 2017) and motivation (Robnett & Leaper, 2013). Moreover, research has even shown it influence girls in a positive way if other girls in their class also like STEM (Raabe, Boda, & Stadtfeld, 2019).

Students' STEM self-efficacy influences decision of further study (Jansen, Scherer, & Schroeders, 2015; Brown, Concannon, Marx, Donaldson, & Black, 2016). Social Cognitive Career Theory (SCCT) (Lent, Brown, & Hackett, 1994) suggests that people are neither controlled by their environment nor are they totally independent and each one has the capability to determine what to select but perceived self-efficacy influences the selection process (Bandura, 1989; Bandura, 1982; Bandura, 1977).

Stereotypes can shape young person's attitudes and diverse fields of STEM can have different stereotypes (Cheryan et al., 2015) which can appeal differently to different persons. Engineers and especially computer scientist or IT persons are often connected to nerdy male types that are not appealing to all but might attract some. Berge, Silfver, and Danielsson (2019) analysed nine different Engineering Mechanics programme websites and their result was that they expose stereotypical norms regarding gender and age. Powell, Dainty and Bagilhole (2012) conclude in their paper that women are aware of "masculine" stereotypes in many jobs but at the same time claim that these jobs are for everyone independent of gender.

The model in figure 2 from Master et al. (2017) shows some of the influencing factors and the situation regarding girls and STEM.

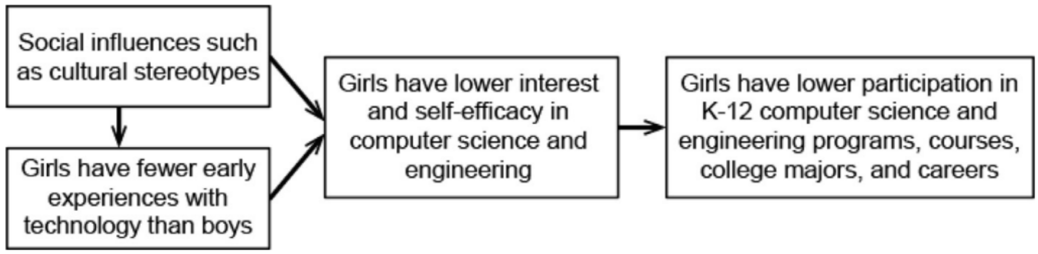

Figure 2. Cultural stereotypes and gender differences in early experiences contribute to gender differences in motivation in computer science and engineering. (Master et al., 2017, p. 94).

The need of belonging is important, so stereotypes need to be diverse enough to attract all students (Master et al., 2017). Experiencing support and encouragement from friends and family can support academic success and predict adolescent girls' motivation in math and science (Robnett & Leaperm, 2013). In a research (Lewis, et al., 2017), with data from nearly 3000 students with focus on pSTEM (p=physical sciences), the main conclusions are that women question their ability more than men and feel less sense of belonging. The sense of belonging outnumbers other ordinary explanations for women's reasons for keep going on in pSTEM.

The objective of this study was to better understand female engineering and computer science students' attitudes when they chose their studies and explore present situation in the two subjects. It is of interest to know what was and is the influencing model and what has been of support after they started their studies.

METHOD

Participants

The participants were a non-probability convenience sample, i.e., a group of students easy to contact for the author. The department office at the School of engineering and School of computer science at Reykjavik University were contacted and asked to provide female student e-mails. Also, female teachers in both departments were asked if they could point out female students that could be contacted. The female computer science student's association, /sys/tur, and the engineering student's association at RU were asked to advertise for participants. Totally 55 female students were contacted and 13 (24%) replied, 10 (28.5%) from computer science and 3 (15%) from engineering. The response rate was rather low and did not give the possibility to compare the groups.

Measures

It was decided to use e-mail to send out the questionnaire because after COVID the University is offering recordings of teacher's presentation more frequently and many students prefer to study from home and are not attending to the university building regularly. At home participants can answer and complete the questionnaire at their own pace which can be convenient and deliver written responses which can save time. Some can even feel less social pressure as there is no visual or non-verbal judgmental cues which can also reduce the influence of the interviewer. Thus, it was hoped that by using e-mail would give more representative data. The questions were as follows:

> 1) When did you become interested in engineering/computer science and what do you think had the most influence on you, was most motivating? 2) When did you decide to start studying engineering/computer science and what do you think had the most influence on that choice, was the most motivating? 3) Which role models do you think have influenced your choice of study? 4) Did you feel that something hindered you in your choice, even discouraged you? 5) How are you doing in your studies? What do you think has motivated you and what has even hindered you in your studies? 6) What role models, if any, do you think you have in your studies? 7) Do you think that being a woman has had any effect on you in your studies and how few women are in the same study?

Procedure

An e-mail was sent to students in engineering and computer science with an introduction letter where they were encouraged not only to answer the questions but to discuss the topic openly. A reminder was sent twice. The answers were collected and separated from the student's names, and answers for each question were grouped together and analysed.

RESULTS AND DISCUSION

To gain interest and decide to study a STEM

The first two questions were related and the answers will be discussed together. Six of the women reported that they were interested in the subject from early on and the inspiration, for most of them, came from playing computer games that fathers and/or brothers had introduced to them or as one said:

> I would say that I first got interested in computers when I started playing video games with my older brother. He got his first computer when I was 5 years old. Since I was quite young, I only got to play games like Bubbles and similar games on Leikjaneti [Game network]. With increasing age, I then got to play more and got his PlayStation 2 computer into my room when he upgraded to a PlayStation 3. Then I started playing even more games and started thinking more and more about what was behind the making of these video games. I say that the video games I played and my thoughts on them were the trigger for me to become interested in computers.

It is noticeable that she did not get a new PlayStation, but her brother did and she got his old one. This may be part of the reason why boys are more confident than girls regarding their technical abilities and computer skills even from an early age (Zviel-Girshin, Luria, & Shaham, 2020; Matthiasdottir, 2018). One of the women mentioned that when she was 12 she learned how to use Excel and that sparked her interest, one mentioned that her father was a computer scientist and introduced her to computers and taking a programming course in secondary school got one of them interested along with films and TV series with super girls hiding behind screens hacking into computer systems.

Seven of the women mentioned that they got interest rather late, and two of them in upper secondary school when they did well in math and science or as one said:

> I'm in mechanical engineering…Got interested after taking a physics course in high school. I have always been interested in mathematics since elementary school and always did best in those classes.

Many of the participants even decided just before they applied what to study. It is interesting that three of the women said that they did not get interested in the subject until after the started their study and mentioned courses that flashed their interest. Anyhow, some of them were content after their decision or as one engineering student said:

> In high school I did very well in science and math, getting good grades and doing well was motivating. I decided during my last year of high school, at the age of 18, to choose a graduate program based on math and science. I made the decision based on what opportunities I would have in the future, then the program had to give me the option of a well-paid job that could be done anywhere in the country.

One of the women recognised in her job that many time-consuming tasks could be automated by help of computers and pointed that out to the technical department. To be acknowledged made her want to learn to do it herself so she got into computer science. To lose a job in COVID was also mentioned as an incentive to study. One mentioned that films about hacking had always interested her and the computer classes at school were fun but she thought computers were not for girls.

The answers are in line with the literature. Some young persons are aware of their interest at an early age and know what they want in the future while others are in doubt, even all their life. We can look at children's life circle as school, family and community and these three settings are the main factors affecting their interest to study STEM (Lent & Brown, 2006). Research have indicated that interest in math and science is one of the reasons for females choosing engineering and applied engineering (Matthiasdottir, 2018; Matthiasdottir & Audunsson, 2022) but some just want to try to study engineering (Matthiasdottir, 2018). As mentioned before, research have shown that females are older than males when they decide what to study at university (Matthiasdottir, 2018; Matthiasdottir & Audunssson, 2022).

The obstacles

Here four of the women did not report any hindrances or obstacles in their environment but others did. COVID was mentioned three times for changing the situation, they could not attend school, especially lab sessions, and there was not enough opportunity to study at home because they had children that could not to go to school during COVID. Peers negative attitudes was also mentioned as an obstacle or as this said:

> The only thing that has been a obstacle is when men don't believe in me because I'm a woman, but then I always end up having to prove myself and then it's not an obstacle.

It was also mentioned that more online programs should be offered because it gives those who have difficulties in attending in-house classes opportunities to study, e.g. older students, students that need to work while studying and students with young kids. Not to be able to study online was considered to be an obstacle for women.

Academic achievement

All except one of the women claimed that they had been doing well or very well in their studies although some courses were demanding. What has motivated them is different, one said it was the will to finish the study and show people that she could do it, another mentioned to get a good job when finished. One mentioned especially /sys/tur, the girls society at the computer department, to participate with them gave her the opportunity to meet other women which made her feel she was not alone in the program. Family and friends were often mentioned as the main support as well as teachers that have a real passion for their work or as one said:

> I have done very well in my studies. I think the friends I have met [in the program] are the most encouraging to me, we are able to learn together and get each other through the most difficult phases.

Sadly, the male classmates could be discouraging which in at least three cases affect their female classmates' self-esteem and courage to keep on. Here are two examples from computer science students:

> What has perhaps hindered me the most in my studies is the way men, or preferably boys, often treat people. There are a lot of group projects where we are put into "random" groups and I end up with some guys who talks to you like you don't know anything. It is very discouraging to work into such groups.

> From time to time, I have felt very lost in my studies, especially in group work where you might end up with a lot of boys in a group who you feel are much smarter than you because they really just talk the loudest.

Role models

Role model play an important part in shaping attitudes and awareness and research have exposed that stereotypes can influence gender disparities as girls are early less attracted than boys to stereotypes in engineering and computer science (Master, Meltzoff & Cheryan, 2021). In this group of women five reported they did not have any role models apart from a family member or friend (grandmother, mother, father, sister, brother, husband and friend) who encouraged them to study further, not STEM per se, but to go to university. All the same, the decision was often built on their own internal motivation as one said:

> I wouldn't say that I had a specific role model in mind that influenced my choice to study computer science. It was more my own stubbornness to choose something that some people around me might have expected me not to be able to do. I have always been keen both to prove to myself that I can do things and also to prove to others. My role model in choosing a good education outside of my comfort zone is my mother. She has always been determined in her studies and persevered despite obstacles.

When it comes to what to study the role models come from all around, the people in their environment, a programming teacher was mentioned, engineers in the family, friends that had graduated with similar education, discussion in society and in social media, and one mentioned a female engineer that is a popular social media influencer telling about her work and family life. Female teachers seemed to be important role models mentioned by five of the women:

> The role models I have had in my studies are the female teachers who have taught me. You often feel like the study is rather masculine, but when you have a woman as a teacher, you somehow feel more secure. It's admirable to watch them and I think it's great when they share their story.

Role models are also found in females that have already graduated and are working in the field and a male role model was only mentioned twice, a father and a teacher but as one said:

> However, the coolest role models who personally inspire and motivate me the most are the girls I've worked with in group work during my studies.

The importance and influence of role models is clear in this group, they feel the stereotypes but they see support in other women around them although there are not many of them. This one gave a good description of the influence of a stereotype and how this influenced her self-confidence:

> Probably the stereotype of a computer scientist/programmer. In most movies and TV series, there are some gorgeous male nerds who live in their mom's basement and just play video games. I remember my friends' reactions when I told them I was majoring in computer science. They thought it was very nerdy and immediately started asking if it wasn't just boys who went into that profession. I then started to feel a little insecure about the choice and whether I would belonged in computer science.

Stereotypes can be a barrier for choosing STEM subjects but female role models can escalate the sense of fit in and support the ideas about how to succeed in STEM, e.g. with hard work (González-Pérez, Mateos de Cabo & Sáinz, 2020). Gender stereotypes and biases influence kids from early on (Van Tuijl & van der Molen, 2016; Alam, 2022), thus, to change societies attitudes and support is one of the factors needed to work with. It was often mentioned that the participants considered the study to be difficult and might not be for women, supporting the two stereotypes. It is clear in the present study that stereotypes have influences and manly in a negative way.

To be a woman in STEM

The feeling of belonging supports students to stay in their study, other students and the teaching play a big role in creating good conditions that can influence the feeling of belonging, one described her situation like this:

> Yes, there are a lot of people in computer science who are very smart. I often feel that I am not in the same place as many people who get 10 [out of 10] in everything. I think this program is very difficult and I don't think the teaching is good enough, I think the teaching is for people who have a good knowledge of programming or people who have been programming for a long time. I often feel that I am not doing well and I often feel that I do not belong in this program.

Four of the participants did not experience that being a woman had much influence on them and one even said that being much older than fellow students were more difficult than being a woman but anyhow they were aware of the gender unbalance and gender difference. Two considered it to be encouraging and empowering to be a woman in STEM but not all were content in their study. One did not find many women to contact in the program but one found a support in fellow female students and friends in the /sys/tur or as she said:

> I have surrounded myself with female friends in the program [in /sys/tur] and therefore do not experience the gender difference. Although it is clearly there.

And one said:

> I don't know about learning, but you can feel how few women there are in the program. Everything somehow revolves around the males in the program and there is a lack of this compassion that you are so used to as a woman.

The others had other stories to tell, some even sad, they did really feel they were looked down at and needed to proof them self's constantly which influenced their self-esteem and well-being as this comment shows:

> … I would say that being a woman in the program sometimes had an impact. I haven't had anything demeaning said to me outright because I'm a woman in this program, but I've had a look at me and I've been treated differently. These expressions and this behaviour did not make me feel good about myself and have prevented me from seeing myself and my abilities correctly.

And one said

> It's hard to explain but many boys in the program have annoying prejudices when it comes to working with women and the manifestation is either that they immediately decide that they can't be "themselves" and it takes a long time to win [their] trust which is very inhibiting in group work, some are very arrogant and have a great need to appear to be superior (mostly unfounded) and prefer women to take care of secretarial jobs, e.g. completion and reporting.

Instead of feeling of belonging in the group these women seek for feeling of belonging to same sex group and seek support and acceptance among other female students.

CONCLUSION

We need and want more people, especially women, to study engineering and computer science and we need to act to change the present situation. What to do and when to interevent to transform the circumstances depends on what we consider to be the most influencing factors. Recent studies have emphasised three factors, *environmental factors*, *factors at the school level* and *factors at the student level* (Van den Hurk, Meelissen & van Langen, 2019). It is also important not only to get female students into STEM study but also to keep them in the program and both the content of the program and the teaching methods are important but we cannot forget their fellow students.

In the present study women experience the study environment differently where the majority of the students and teachers are male, for some it does not matter much but for most of them it influences their well-being in the program and can harm their self-confidence. The answers from engineers and computer science students where similar but computer science students reported more negative attitudes from the male students.

Two stereotypes have been identified that affect the level of enrolment and preservation of women in STEM fields as they are believed to decrease female interest in STEM. First is the impression that STEM subjects are hard to study and manly for brilliant or gifted students to flourish and secondly the characteristics of scientists and scientific jobs (Shin et al., 2016). Same-sex role models are believed to have beneficial influence, e.g. be a "social vaccines" protecting against stereotypes but do not change the stereotypes (Dasgupta, 2011). They can serve as a buffer for damaging experience in STEM, improve women test performance (Marx et al. 2009; Marx & Roman 2002; McIntyre et al., 2003) and strengthen the sense of belonging (Cheryan et al., 2009).

The feeling of belonging and being accepted is important for students (Ito & McPherson, 2018), it shapes their identity and influences their sense of developing in their education. For women, feeling of belonging can have a positive impact on educational success and retention in STEM (Rattan et al., 2015). Uncertainty can have harmful effects on students' identification in their field, success, persistence, and career ambitions, especially among minority groups. Research have shown that perceived emotional and academic exclusion by other students increases female students' uncertainty in computer science but not male students (Höhne & Zander, 2019).

If we look at the answers in light of Van den Hurk, Meelissen & van Langen's (2019) model for academic choices and persistence in STEM education (figure 2) we see that social environment (family, parents, peers) is a strong influencing factor but also school context (school climate) and social context (cultural environment). We do also see that malleable and non-malleable student characteristic are often mentioned by students. This research supports Van den Hurk, Meelissen & van Langen's (2019) conclusion that programmes to improve the gender situation in STEM should focus on knowledge, ability, motivation and feelings of belonging.

Limitations and opportunities

To use an e-mail to send questionnaire can be considered as a limitation, it might have been possible to gain more detailed information with face to face interviews. Anyhow the results are in line with previous research and give more insight into why women choose to study engineering and computer science and give ideas about what is important to work at to encourage more females into STEM studies and to keep them in the programs. This calls also for more investigation into what projects or actions to get more female into STEM have been successful so far and where we should go from now.

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LESSONS LEARNED FROM TEACHING AND TUTORING DESIGN THINKING TO ELECTRICAL ENGINEERING STUDENTS

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ABSTRACT

To deal with societal challenges, future engineers need new skills and competences. Design thinking is one such skill. The project Future Technology Studies (Dahle Øien, 2021) aimed to develop the study programs in technology at Norwegian University of Science and Technology (NTNU) according to future technological development, societal challenges, and industry needs. One of the findings from FTS was that technology students should learn Design Thinking. In this work, we study an implementation of design thinking in an electronic engineering study program. Specifically, we use three perspectives, students, learning assistants, and teachers, to study how they experience the introduction of a cross-disciplinary topic in a domain-specific project course. The target group were electrical engineering students (N=117) who did a user-centered electronic system in a project-based introductory course in electronic systems design. Drawing on findings from a web-based questionnaire from students (N=67) and interviews with course staff members and tutors (N=13) our findings show (1) that more work is needed to improve the course description, activities, syllabus, and student evaluation and (2) the importance of making the purpose and goal of including design thinking in the course clear for the students.

KEYWORDS

Cross-disciplinary teaching, future technology studies, design thinking, electrical engineering, design, CDIO, standards 1,3,5,7,9,11

INTRODUCTION

Today, technology is intertwined with almost all areas of our lives, affecting people's daily lives both in seen and unseen ways, and continuously enters and changes new domains of society. Society and society's challenges has grown increasingly complex as the rate of technological development has increased. Solutions to these challenges require more than a technical understanding, but also an understanding of the societal and environmental context of the problem. Thus, for the modern engineer, technical competence is required, but not sufficient to apply their knowledge to the benefit of both people and environment. To be able to educate the modern engineer we need to view the process of engineering as more than the simple application of science. Figueiredo (2008) suggests that there are four dimensions to an engineer: the engineer as a scientist (basic science), sociologist (social science), designer (design) and a doer (practical implementation). Engineering needs to be seen as a process where knowledge from these dimensions is used based on the specific context of the problem the engineer is working on. Traditionally, engineering education has had a strong focus on the understanding of basic sciences, with practical implementation of basic science being introduced towards the end of a degree. However, there is an emerging understanding of the need for the other two dimensions in engineering education. The needs of the modern engineer and modern engineering education has recently been looked into by the project Future Technology Studies at NTNU (FTS) (Dahle Øien, 2022) and highlight the need for strengthening the engineering students' competences within the design and social science dimensions above. FTS ran between 2019 and 2021 at NTNU with goal to «facilitate NTNU's study portfolio in technology to be as closely aligned as possible with technological development, societal challenges and the needs of business and working life in the period from 2025 onwards» (Bodsberg, 2020). In addition, the reports Engineering change – The future of engineering education in Australia (P. L. Lee, 2021) and Navigating the Landscape of Higher Engineering Education from the Technical University, Delft (Kamp, 2020), both highlight that future engineers need competences outside application of science.

These reports predict that the futures for engineering work are characterized by more complexity, more multidisciplinary, greater accountability, more focus on sustainability, and being performed on a global arena. Future expectations of professional engineers are that they have skills and competences that excel the past engineering work. Some of these skills are human focused impacts, design thinking, problem finding/framing/solving, multi-disciplinary collaboration and communication, stakeholder interaction, creativity, and imagination (Crosthwaite, 2021). All of these are important elements of working on projects with design thinking (DT) as a framework.

Design thinking is a framework that gives students and educators structure and tools to address problems with unknown solutions and wicked problems. The framework is a human-centered iterative problem-solving approach for developing innovative technologies, products, and services. The approach involves (a) identifying a problem and map and understand user needs, (b) developing concepts and proposals for solutions through creative development methods, sketches, and prototypes, (c) systematically testing the solutions on end users, and (d) improving the solution through iterations of the process. The framework, which exist in numerous variants and modifications and is usually explained through the five phases described in Figure 1.

Figure 1: Phases and example methods of the design thinking framework

The topic of teaching problem solving and more specifically design thinking to engineering students has been researched extensively from several angles for decades, including – but not limited to, researchers in the fields of design education and CDIO.

Previous research have – among other things, looked at comparing junior and senior engineering students approaches to solving open ended problems (C. J. Atman et al., 1999) (C. Atman et al., 2005), comparing engineering students and expert design practitioners (C. Atman et al., 2007) and how students' design processes differ and develop through the course of an engineering program (Cardella et al., 2008). Other researchers have looked at course design and didactic aspects of teaching design to this group of students (Lilliesköld & Östlund, 2008) including strategies for learning (Vattam & Kolodner, 2008). Similarly, observations on how to how the topic of design thinking may find its way into a CDIO context can be found in the works of Fai (2011), Ping (2011), Lee et al. (2014) and many others.

While there have been a number of articles exploring the effects of teaching and tutoring on the design thinking competence among engineering students, here we report on the experiences from introducing design thinking in an already established project course, focusing on the implementation itself from three perspectives – the student, the student learning assistant, and the teacher.

In this work, we have introduced design thinking in a first-year project course given to electrical engineering students through a collaboration between departments of design and electrical systems at NTNU. While similar studies have had a focus on the learning outcome, behaviors or competencies, the aim of our study has been getting more insight into the process of integration. Firstly, to gather data from student tutors and teaching staff about their experiences related to teaching and tutoring a cross-disciplinary topic to a new group of students. Secondly, we wanted student opinions about learning and using a cross-disciplinary topic to solve a problem in their own domain.

Design Thinking for technologists

As a case to study how DT can be integrated in engineering education, we used a five-year master's degree program in Electronics Systems Design and Innovation (MTELSYS) at NTNU. At this program students learn how to design and develop electronic equipment and systems. The study program has a foundation of mathematics, physics, and programming in combination with digital technology. The study program starts with a basic course in Electronic System Design (ESD) for its approximately 120 students (Department of Electronic Systems, NTNU, 2023a). The course is organized around the first phase of a larger innovation project in collaboration with an external company or organization with a real-world problem (Department of Electronic Systems, NTNU, 2023b). The students work in groups to make a prototype, using microcontrollers, sensors, and actuators, that can contribute to a solution to the collaborator's problem, with the goal of learning how to design simple electronic systems. ESD is divided into two parts: the introductory weeks and the innovation project. The introductory weeks aim at giving the students the basic competency needed to be able to contribute to the innovation project in the second part. The introductory weeks have until now focused on giving students practical skills within electronics through several short microcontroller-based exercises.

To counterbalance the heavy technology focus in the course and to make the project results more useful for its stakeholders, the course coordinator (co-author Bolstad) reached out to an employee at Department of Design (co-author Alsos), who was teaching a comparable course for industrial design students (Alsos, 2015), to see if they could exchange ideas. As a result, in 2019 the two course coordinators started an undercover learning assistant (LA) exchange program where LAs employed at the industrial design program were lend out to tutor students at the electronic system design program – and vice versa. Coming from different Faculties (Architecture and Design / Information Technology and Electrical Engineering) the undercover label was given to avoid any bureaucratic, organizational, and economical obstacles. In 2021 Design Thinking was introduced formally as a part of the curriculum.

The motivation for introducing DT in the ESD course was four-fold. First, it was observed by the teachers involved in the course that while the students created well-crafted electronic systems, they did not necessarily create systems in line with the needs of the external collaborator. Second, the competences gained through learning DT would make the course more constructively aligned with the course's intended learning outcome of giving the students a "beginning identification with the role of technological problem solver and innovator" (Course - Electronic System Design, Basic Course - TTT4255 - NTNU, n.d.). Third, it has previously been found that the students have a limited view of design and considers design as mainly being related to aesthetics and other exterior aspects of the prototype and reveals a belief that innovation is mainly a technological challenge thereby limiting the cognitive room available to the students when asked to work as engineer in the innovation project (Bolstad et al., 2021). Lastly, the NTNU project Technology Studies of the Future explicitly mentioned Design Thinking as competence that technology students should learn (Dahle Øien, 2021b, p. 13).

The DT module was called Design thinking for Technologists and was implemented as a 2,5 ECTS micro module. It was not a standardized, stand-alone course of the usual 7,5 ECTS, but was dependent on running in parallel within an existing project-based course, a kind of host which it could live in symbiosis with. The module took advantage of a pre-existing and not too specific curriculum and introduced new topics into the syllabus, but without changing the overall structure of the course nor the type of assessments. The learning outcomes and curriculum of the module was simplified compared to other design thinking courses, and carefully adapted to the target group. The number of methods they learned within each stage of the design thinking process was reduced to a minimum. In addition to teach and tutor DT framework and methods to the technology students, the aims were also to test out the integration of a DT micro module into an existing project-based course, to explore new financial distribution keys and performance allocation, and to encourage interdisciplinary collaboration and coordination between different faculties.

In conjunction with the introduction of DT, as described in this work, the introduction weeks were reworked. Instead of short exercises in week two and three, the students use DT in short one-week projects. There, they were asked to empathize with end users, define the problem, and ideate, prototype, and test solutions based on microcontrollers while having access to instructions on how to create useful parts of the prototype system, for example how to communicate wirelessly between microcontrollers. For more details on the structure of the course see (Lundheim et al., 2016). In the rest of this paper, we summarize the assessment of the Design Thinking pilot that ran in parallel with the ESD course during the fall semester of 2021.

METHODS

The aim of this study was (1) to assess whether the design thinking module gave the candidates competences in design thinking that enables them to develop user-friendly technology, and (2) to find out if the concept of micro modules integrated into an existing course. We used a two-pronged approach to investigate the student and staff experiences with regards to testing out the design thinking module. Staff, student tutors, and student representatives were interviewed with the goal of getting an in-depth understanding of the subject matter. We also conducted a survey with students at the end of the course and as part of the general course assessment. The purpose was to shed light on the design thinking competency development by students.

All the students in the course (N=117) were asked to take part in a course quality survey at the end of the course. Of these, 57 % participated in the survey (N=67). They answered a subset of 31 questions (from a total of 96 questions) that were directly or indirectly relevant for their experience with learning about DT. The students were asked on a five-point scale how much they agreed on various dimensions about the course (such as prior knowledge, satisfaction, relevance for study program, difficulty level, workload, information, teaching, supervision, learning environment, resources, project work, assessment, etc.). Some of the questions were directly relevant for the DT module (such as the prior information about DT, teaching, and tutoring in DT, the learning environment in DT, use of DT in the projects, the assessment of DT, and any other comments regarding the teaching, tutoring, and assessment on the topic of DT). In this work we present the results from a subset of these questions, specifically the perceived quality of the teaching and resources, the reported development of understanding electronic systems and DT, and in which arenas of the course this understanding has been developed. The subset was chosen based on the research questions and the thematic analysis of the interviews. To check for statistical significance the Wilcoxon Signed-Rank test is used, which is a non-parametric version of the paired t-test, with a significance level of 0.05.

Using guidelines and an approval from the Norwegian Centre for Research Data (NSD), we interviewed two reference group members (N=2) out of four total reference group members, eight learning assistants (LAs) (N=8) out of ten total LAs, and three teachers (N=3) out of four total teachers. They participated in a qualitative, semi-structured, and open interview about their general experiences in being taught/teaching and tutoring design thinking and their suggested improvements. In total, 13 persons within these groups, in including the co-authors of this article, were interviewed by the first author of this article. To avoid any bias, the coauthors were not involved in the development of the interview protocol, data collection, transcription of data, nor thematic analysis. The interviewees came both from the Department of Electronic Engineering (N=10) and from Department of Design (N=3).

After conducting the interviews, we transcribed the recordings into anonymized text for further processing using NVivo using thematic analysis (Braun & Clarke, 2006). We carefully examined the interview transcriptions to identify patterns and common themes using a six-step process: familiarization, coding, generating themes, reviewing themes, defining, and naming themes, and writing up. The quotes used here has been translated from English to Norwegian by the authors.

Limitations

There are several limitations with the approach used here. In the survey, we use self-reported data on learning, which might not reveal the true learning as they are novices within the field. With regards to the interviews, using reference group members as interviewees can be beneficial as they should have an overview of the general views of the student group. However, as they have self-selected to be a part of the reference group, they might be especially motivated or interested in the subject.
RESULTS

When asking the students about the quality of the DT module as compared to the rest of the course, they report a lower quality for the DT module across all measured areas as seen in figure 2A, with the differences being statistically significant. The largest differences are seen with regards to the reported quality of the location and resources. As the location was constant throughout the course, the difference must be a result of the quality of the resources available. Larger differences are also found for the quality of the use of DT in the introductory weeks, in the innovation project, and in the assessment, compared to the other elements of these activities.

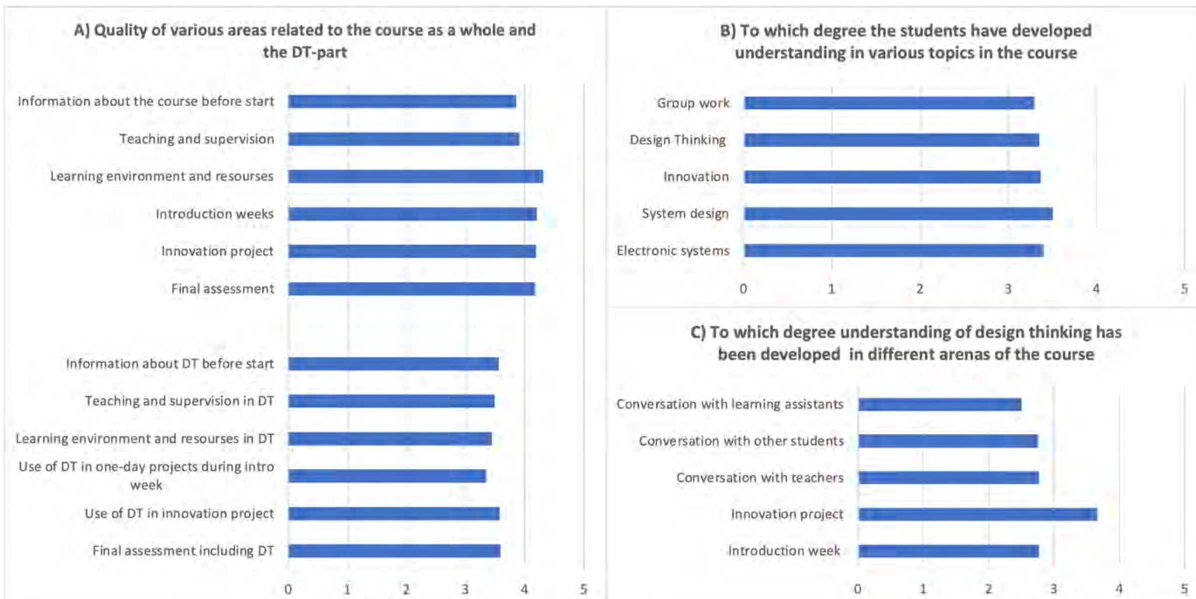

Figure 2: (A) The reported quality of various aspects of the course in general and the DT module in particular. (B) The reported development of understanding for central topics in the course. (C) The reported development of understanding for central topics in the course

Despite the reported differences in quality, when asked to report their development of understanding of topics central to the course such as electronic systems, systems thinking, innovation, groupwork and DT, the differences are small (figure 2B). The difference between the developed understanding of electronic systems, the central theme of the course and associated program, and the developed understanding of DT is not statistically significant. Examining the understanding of DT further (figure 2C), we find that the students report that their understanding developed the most through working on the innovation project, more than through the activities in the introductory weeks or through conversations with teachers, students, or LAs.

We then went from looking at the DT learning experiences among the students in the survey, to looking at the individual teaching or tutoring experiences among the teaching staff (TS) and learning assistants (LAs) in the interviews. Our key questions centered around what the participants felt was positive with the teaching/tutoring task they had been through, and where they felt the DT-module had room for improvements. From a general perspective, we noted that very few of the interviewees had negative experiences to report, and that there were a wide variety of constructive suggestions on how to improve the module.

Starting with the former, LA1 from the department of design stated that first year students, unfamiliar with design thinking (DT), will more easily enter a state where they do not consider the end goal of the project, ending with poorly considered features in the solution they are designing and building. Introducing DT and using LAs with DT background gives the students a reason to think about the end-user value their project creates:

> *So, I think it is only useful for them to be confronted with the fact that someone explicitly asks you those questions, such as "why have you chosen to do this? And […] what value does it actually create? I think at least as first graders – it's very easy for them to fall into that "here's a really cool thing to do - we have to do it here" mentality. And then they just do it, and then they build on it with features, and then it's ... it just becomes a mess*

Several LAs recruited from the Department of Electronic Systems (IES) gave us similar feedback about the positive aspects of the course, highlighting the DT activities in the introductory weeks as important for the success of the DT module:

> *I think it was good that it was planned and that there were introductory weeks at the start, […] then they have a little understanding of what the level of ambition is placed and what they can achieve.*

Furthermore, LAs also note the importance of focusing on user-centered insights and being able to take stakeholders in to account for these students' futures as engineers:

> *[…] now it has also come to the point where you have to think about the consumer... it gives some insight into what problems actually come up... here, there is a lot more we can actually think about, really.*

Through using LAs from the Department of Design (ID), in addition to the learning assistants from IES, the students receive guidance and support, helping the students start to develop the mental pathways necessary for DT. The first one of the two reference group members in the class we interviewed, focused on the inspiring learning assistants from ID as one of the key positive aspects of the module:

> *… they showed off their projects and we have received reports from design students to see how they design it and think.*

One of the members of the teaching staff (TS1) at the Department of Electronic Systems (IES) we interviewed, also call attention to how DT incentivizes students to reflect on their goals through the empathy phase and its focus on the end-user. Furthermore, the staff member echo the statements by the LAs, highlighting the introductory weeks as important for the DT module, where the one-day projects gives the students an understanding of the process and the usefulness of DT:

> *…The fact that we include is this empathize phase that comes at the very beginning where you justify… I think that has worked very well, that the students have to justify the need for the solution before they start thinking about ideas and before they start implementing the ideas or the concept/solutions. […] I feel that the students have gained a lot from that…*
>
> *[…] and when we facilitated those one-day projects in the intro weeks, where they had to go through... within one day they had to go through the whole loop, also test by making a cardboard prototype in just one day... And these were students who were only... they haven't had any technical training before this, so they really can't do much - and I felt that worked very well, and*

I think that in a way they got to know the power of the design thinking module and -process. I definitely feel that we have to take that forward.

TS1 also commented on the potential improvements of the design thinking module, including maintaining the pressure on the students to connect their effort to empathize with the end-user at the start, with the project´s final result:

[…] they must show very clearly that the prototype and the solution they end up with, it is connected to the work they have done in connection with "empathize" and the idea generation phase and not least the testing phase and that it (the work) is connected in several iterations then. The way the students are now presenting it, there are fairly linear processes up to the prototype, and I think there is clearly potential for improvement there. By trying to permeate that design thinking process further into the subject then - towards the deadline as well, right up to the deadline.

TS1 was not the only one with suggestions for improvements. The first LA we interviewed suggested that the interface/transition between the course and the design thinking module needs work, but had no specific suggestions:

...I simply think that finding a slightly softer transition between design thinking and .... the technical aspects of the subject. I think that would have helped a lot.

The second reference group member also gave us a suggested improvement when noting that the placement of the lecture about design thinking could have a higher impact if it was move to an earlier place in the course:

[…] perhaps move that lecture a little earlier or do it in a different way, then perhaps even more would have entered that basic knowledge and it would have been easier to use them.

One of the LAs that reported to be an experienced 4th year student, highlighted the importance of being physical close and accessible to the students:

[…] the most important thing for the subject ... and for you to use us learning assistants because it is very nice for them, is that they see us... and that we are very accessible. Because of that, we noticed a difference this year as well. That the groups that sat inside the [space reserved for the course], they used their learning assistants much more than the groups I had that sat outside...

Learning assistant number five from MTELSYS, also commented that the course could improve by collecting and recycling materials for the prototypes, and improve by making it possible to pull them apart again, for yet another re-use of the materials used:

And one more thing. You must remember improvement. They have taken... put now, the now to be environmentally friendly when we see that there is a new project every year. Then it was easier to be able to use fins or one thing or another, or if the school could bring in things that can be reused then, because it becomes more like that, everything is done there, and then it is glued, and then things become torn apart and unfortunately cannot be used again. Because it should also be in the future.

Reflections-On-Action

As a form of reflection-on-action (Schön, 1983), the second and third author of article reflect as follows on their own actions of creating and testing the design thinking micro module:

Our purpose of the module was to give technology students competence in design thinking so that they could learn to make technology with value for individuals, organizations, and society, not only for the sake of technology. Based on our impression, we think that we succeeded in introducing design thinking to the engineering students and changing the way they think about the importance of end users. However, varying degrees of application of DT by the groups in the innovation project was observed, resulting in prototypes with a diverging alignment between function and real user needs.

One of the main challenges for us was to find a way to fit the design thinking syllabus into the MTELSYS study program. Study programs are usually completely full, and to wedge in yet another course is impossible without taking another course out. In addition, it would not make sense to arrange a design thinking course without a project to apply the design thinking framework. This project should not be any random project but should be aligned with the learning outcomes of the study program. Therefore, our solution was to create a micro module that could float on top of an existing project-based course.

Because of the size of the micro module the students could only learn a limited number of methods from the design thinking framework. We had to carefully select a few methods in each phase.

Flexibility from all involved parties was essential to allow the close course integration of the DT module. The prior collaboration with the LA exchange and the personal relation and mutual respect we developed was important to make this collaboration possible. This initiative started as an undercover operation over several years but was later normalized through an official pilot.

DISCUSSION AND CONCLUSION

Building on the survey, interviews, and reflection on action, we will in this section discuss the effect, design, and transferability of this module. Despite the students reporting that they experience the quality of the DT aspects of the course as lower than the rest of the course, they still report the same degree of development of understanding of DT as of electronic systems. The lower reported quality might arise from a frustration from engagement in DT concepts foreign for the students. In the interviews, the Las and staff highlight how the integration of DT forces the students to make new mental pathways and make considerations that might be counter to their instincts as first-year engineering students, matching the intended goals of the module. This frustration is also found when business students are exposed to DT project work (Glen et al., 2015) . The ability to manage frustration and uncertainty and integrate new concepts are important skills that an engineering program needs to develop in its students in order to prepare them for a world with wicked engineering problems (Dahle Øien, 2022). However, too much frustration will lead to a disengagement with the DT in the students, which was observed in some groups, especially for students with low tolerances for uncertainty. Integrating DT in a first-year course needs to focus on simple activities and manageable goals to achieve a degree of frustration in the students that encourage the engagement and reflection that create new mental pathways. The activities in the module described in this work seems to be close to finding this balance as the reported development of understanding is similar to other central elements of the course.

We observe that the most important arenas for the development of understanding of DT are the introductory weeks, as reported by LAs and staff through the interviews, and the innovation project, as reported by the students in the survey. That the students report the innovation project as the central learning arena is natural as the majority of the semester is spent working on the innovation project. However, from the interviews and own experiences we believe that the learning from innovation would be severely limited without the introductory weeks. They provide the necessary mental scaffolding to allow the application of DT on the real-world wicked problem given in the innovation project. However, there are signs that this scaffolding needs further improvements, as there are signs that the students did not work through iterations as intended, but rather linearly.

To increase the understanding of DT as a result of the module, there needs to be an even closer integration of the DT and technical aspects of the course, with more assistance from LAs and supporting activities. In this regard, using a course and a project relevant for the study program is essential. Using skills developed in a general context can be cognitively difficult to apply intuitively to other specific contexts (Perkins & Salomon, 1989). Therefore, if we want to give the students the ability to utilize DT on problems they will face as engineers, teaching them within a relevant context is important.

A closer look at the constructive alignment (Biggs, 1996) in the course and to what degree the assessment is aligned with the learning activities and tutoring may also be relevant to an improved micromodule in this specific case.

An important goal for the development of this module is the possibility of giving similar modules to other engineering programs. A central challenge for the transferability of the module is the origin of the module in a personal interactions and connections. The module has been developed and tailored for the course over several years and through continual collaboration. One could argue that it will be too difficult or too time consuming to establish such personal connection for every new integration of a DT module. However, the transformation of education, that for example the host institution of this study is facing (Dahle Øien, 2022), requires more collaboration across courses and across disciplinary boundaries. Placing a larger emphasis on creating arenas and situations where these connections can be established might be a requisite for the success of such transformation efforts.

A last challenge for the transferability is the organizational obstacles. IES and ID are located at different faculties. The incentives for co-production of courses across faculty barriers are low, as faculties are independent organizations with their own budget, employees, and courses. Exploring how a culture for integrating, teaching, tutoring, and evaluating design thinking may spread to a larger NTNU audience of programs, courses and staff, should be the goal of further studies.

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ENGINEERING TECHNOLOGY STUDENTS' SELF-REGULATION: A BASELINE

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ABSTRACT

Technology is evolving at a very rapid rate in today's society. Even though engineering students get acquainted with state-of-the-art technological advancements, these often get outdated during the engineers' careers. It is therefore of major importance that engineers learn to learn for a lifetime, in order to train their personal competencies and to keep up with technological innovations. Currently, there is no framework that defines the umbrella competency lifelong learning (LLL). It is certain, however, that self-regulation is a core and malleable competency for LLL. This research presents Flemish engineering students' self-regulation levels, measured using the Self-Reflection and Insight Scale (SRIS). The SRIS consists of three subscales: engagement in self-reflection, need for self-reflection, and insight. The scores are looked at from different angles, such as across study phases and by taking into account background variables like secondary education (SE) type and sex. In general, master students report the highest level of self-regulation. Most notably, students with a more technical SE-background report higher levels of self-regulation in the master year than in the bachelor years, whereas students with a more general SE-background do not. Male and female students' self-regulation is at roughly the same level, but influenced by the underlying subscales.

KEYWORDS

Engineering Education, Lifelong Learning, Self-Regulation, Standards: 2, 3

INTRODUCTION

Lifelong learning has become an important competency for engineers in today's society (Guest, 2006). Even though engineering students get acquainted with state of the art technology as part of their studies, those technological advances evolve at a very rapid rate and can become obsolete long before the engineers finish their careers. In addition, engineers are also expected to develop their professional competencies throughout their careers, as the levels they attain when graduating are not sufficient for the industry (Hirudayaraj, Baker, Baker, & Eastman, 2021). In short, engineers are expected to engage in both personal and professional development and in order to do so successfully, they need lifelong learning skills. As higher education has a great responsibility in the training of engineers, it is desirable that lifelong learning competencies are included in engineering programs' learning outcomes to help ensure that these competencies are adequately developed (Crawley, Malmqvist, Ostlund, Brodeur, & Edstrom, 2007). Ideally, these non-technical competencies are included in the curriculum in an integrated manner as a reflection of their importance (Crawley et al., 2007).

Unfortunately, there is no consensus yet as to what lifelong learning entails precisely, nor as to what competencies underlie it or contribute to it (Qalehsari, Khaghanizadeh, & Ebadi, 2017) (Cruz, Saunders-Smits, & Groen, 2020). Supporting competencies include intrinsic motivation (Lüftenegger et al., 2012), curiosity (Bayrakçi & Dindar, 2015), and goal setting (Kirby, Knapper, Lamon, & Egnatoff, 2010). Self-regulation has been established as a core competency for lifelong learning and according to Lord, Prince, Stefanou, Stolk, and Chen (2012) it can even be used as a proxy for it in educational contexts.

Zimmerman and Moylan (2009) have defined a cyclical model for self-regulation based on three phases: the forethought phase, the performance phase and the self-reflection phase. First comes the forethought phase, in which students prepare for what they wish to learn or do. They may engage in goal setting and planning, for example. This phase is followed by the performance phase, in which the actual execution of tasks occurs, along with self-monitoring and other processes. After this, the student enters the self-reflection phase. At this point the student evaluates their work and outcome expectations, gauges whether or not their goals have been accomplished, and pinpoints what to do better next time. After the self-reflection phase, the cycle is completed by going back to the forethought phase - the student effectively takes their lessons learned into account when preparing for existing or new goals and desired outcomes.

In absence of a complete framework of lifelong learning, this research will utilize self-regulation as a proxy. In order to get an overview of students' lifelong learning capacities, their self-regulation levels will be measured instead. This paper presents a baseline for Flemish engineering students' self-regulation levels and contributes to the future establishment of a possible natural growth model by delivery of the first measurements. Such a model may later be used to help interpret the impact of self-regulation interventions.

In this paper, these research questions will be addressed: (RQ1) What are Flemish engineering students' baseline self-regulation levels? Can any differences be observed between students of different study phases (RQ2), of different educational backgrounds (RQ3), and male and female students (RQ4)? First, this research's methodology will be presented, including context, participants and data collection, processing and analysis. Second, the results will be presented both graphically and in table format per research question. A discussion will follow to shed more light, followed by a concluding summary of the paper and a brief look ahead.

METHODOLOGY

Context and Participants

In Belgium, Engineering Technology students typically follow a three-year bachelor's program, after which they enroll in a one-year master program. We refer to the progress they've made in the university program as their study phase: they may either be in one of their bachelor program years (BA 1, 2 or 3) or in their master year (MA). A questionnaire on self-regulation was offered to students of all study phases at three Engineering Technology campuses (Sint-Katelijne-Waver, Leuven and Ghent).

Secondary education programs are grouped into a few large categories in Belgium. General Secondary Education (GSE, *Algemeen Secundair Onderwijs*), for example, offers more general theoretical courses and mainly prepares students for higher education, whereas Technical Secondary Education (TSE, *Technisch Secundair Onderwijs*) generally offers more practice-based and technical courses.

Survey and Collected Data

Grant, Franklin, and Langford (2002) developed the 20-item Self-Reflection and Insight Scale (SRIS), which consists of three subscales: the need for self-reflection ($n = 6$), actual engagement in self-reflection ($n = 6$), and insight ($n = 8$). In their work, self-reflection is defined as "*(...) the inspection and evaluation of one's thoughts, feelings and behavior*" and insight as "*(...) the clarity of understanding of one's thoughts, feelings and behavior*". Both play a crucial role in self-regulation and the SRIS can thus be used to measure it (Grant et al., 2002). Participants can rate the statements on a 1-5 Likert scale to indicate to what extent they agree with them. A score of 1 corresponds to 'Strongly disagree' and a 5 to 'Strongly agree'. The survey contains both positively worded statements and negative ones. This survey has been validated for use with engineering students by Van den Broeck and Langie (2022). On the one hand, Grant et al. (2002)'s original factor analysis resulted in only two factors: self-reflection (SR) and insight. These results were based on SRIS data from psychology students. Roberts and Stark (2008), on the other hand, confirmed that the three subscales behave as factors for medicine students. As Engineering Technology can be considered a 'hard science' and therefore more similar to medicine than to psychology, the three subscales will be treated as factors for this research. A Dutch translation of the SRIS was used for this research, as this is the native language of most Flemish students.

Students' university ID number and e-mail addresses were also collected, in order to match their results with background variables stored in the university's database. This background data consists of the student's sex as it is listed on their personal ID, the study program they are enrolled in along with their current study phase, and what educational background they have (secondary school education type). The Social and Societal Ethics Committee (SMEC) has approved this use of data in the file G-2022-5676.

Data was collected as part of a lecture and to mitigate sampling bias, the survey was also distributed via the online platform used by the university. Still, students that are not actively involved in their studies in either of those ways may not be properly represented by the collected data.

Data Processing and Analysis

The obtained data was analyzed using R version 4.2.0. In total, 875 survey responses were collected, which corresponds to a response rate of 26.21%. Only fully completed entries were withheld, resulting in 783 usable submissions. Entries were then matched with background data obtained from KU Leuven's database and negative statement scores were inverted.

Based on the students' provided ratings, a score for each of the self-regulation factors was calculated by taking the average over the items loaded on that factor. In addition, an average over all 20 statements was calculated to summarize the students' level of self-regulation as a whole. These averages can take any continuous value in the $[1, 5]$ interval.

To answer the stated research questions, nonparametric Kruskal-Wallis tests were employed. If these indicated that differences might exist, post-hoc paired Wilcoxon tests were run for confirmation. For any differences found, Cohen's d was calculated to gauge the effect size. To this end, the values were compared to the interpretations suggested by Cohen (2013) and Sawilowsky (2009).

RESULTS

RQ1: What are Flemish engineering students' baseline self-regulation levels?

Table 1 presents the baseline for self-regulation as means of the students' scores, per factor and study phase.

Table 1. Engineering Technology students' self-regulation levels (scale 1-5) per study phase.

Study phase	**Engagement in SR**		**Need for SR**		**Insight**		**Self-regulation**		***n***
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
1st (Bachelor)	3.32	0.70	3.40	0.69	3.32	0.59	3.34	0.44	389
2nd (Bachelor)	3.33	0.66	3.33	0.74	3.35	0.69	3.34	0.41	137
3rd (Bachelor)	3.24	0.77	3.31	0.75	3.40	0.67	3.32	0.50	112
Master	3.43	0.80	3.57	0.74	3.39	0.66	3.46	0.47	145
All	3.33	0.72	3.41	0.72	3.35	0.63	3.36	0.45	783

RQ2: Can any differences be observed when looking at students of different study phases?

Figure 1 shows the distribution of scores per study phase. Only slight differences can be observed, with a general increase towards the master year.

In terms of *Engagement in self-reflection*, no significant differences could be found ($H(3) = 3.83$, $p = .28$). However, students of different study phases experienced different levels of *Need for self-reflection* ($H(3) = 11.23$, $p = .01$), with small differences between master students ($M_{MA} = 3.43$) and all bachelor phases ($M_{BA1} = 3.32$, $d_{BA1} = 0.24$, $p_{BA1} = .04$; $M_{BA2} = 3.33$, $d_{BA2} = 0.33$, $p_{BA2} = .03$; $M_{BA3} = 3.24$, $d_{BA3} = 0.36$, $p_{BA3} = .03$).

Insight did not significantly differ between cohorts ($H(3) = 3.81$, $p = .28$) and even though a Kruskal-Wallis test on *Self-regulation* as a whole signaled differences ($H(3) = 7.85$, $p = .05$), post-hoc tests failed to confirm any.

RQ3: Can any differences be observed between students of different educational backgrounds?

Most of the surveyed students had a GSE ($n = 542$, 69%) or a TSE ($n = 231$, 30%) diploma. The remaining 10 students whose educational background was not known were excluded from this part of the analysis.

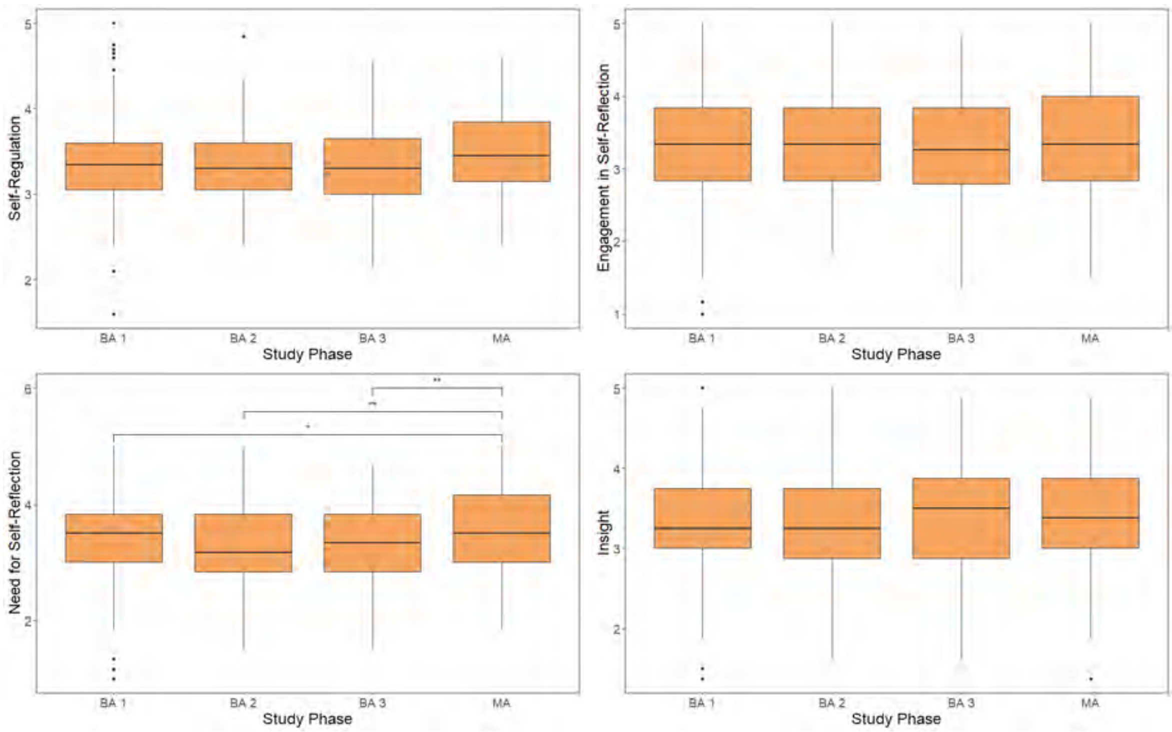

Figure 1. Distribution of scores per study phase. Left to right, top to bottom: Self-Regulation, Engagement in Self-Reflection, Need for Self-Reflection, Insight.

In research question 1, students of all educational backgrounds were grouped together. When discerning between them, it is clear that not all student populations evolve in the same way. Considering GSE students only, no significant differences can be found between the different study phases for any of the factors, nor for self-regulation as a whole. TSE students on the other hand may differ in their *Need for self-reflection* between study phases ($H(3) = 8.06$, $p = .05$) and in their *Self-regulation* as a whole ($H(3) = 11.01$, $p = 0.01$). The former could not be confirmed by post-hoc tests, whereas in the latter case master student scores ($M_{MA} = 3.51$) exhibited a medium increase from bachelor scores ($M_{BA1} = 3.33$, $d_{BA1} = 0.36$, $p_{BA1} = .04$; $M_{BA2} = 3.25$, $d_{BA2} = 0.65$, $p_{BA2} = .02$; $M_{BA3} = 3.19$, $d_{BA3} = 0.70$, $p_{BA3} = .02$).

RQ4: Can any differences be observed between male and female students?

Most of the Engineering Technology students are listed as male ($n = 678, 86.6$%) and the rest of them as female ($n = 105, 13.4$%). Figure 3 shows the score distributions across study phases. Visually, it is clear that females tend to engage more in self-reflection as well as generally feel a greater need to do so. Their reported insight levels are lower than their male peers', averaging out their whole *Self-regulation* scores to be somewhat similar.

Table 2. Male and female Engineering Technology students' average self-regulation levels.

Sex	**Engagement in SR**		**Need for SR**		**Insight**		**Self-regulation**		***n***
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	
Male	3.29	0.72	3.39	0.72	3.39	0.62	3.36	0.45	678
Female	3.60	0.68	3.54	0.73	3.12	0.68	3.39	0.47	105

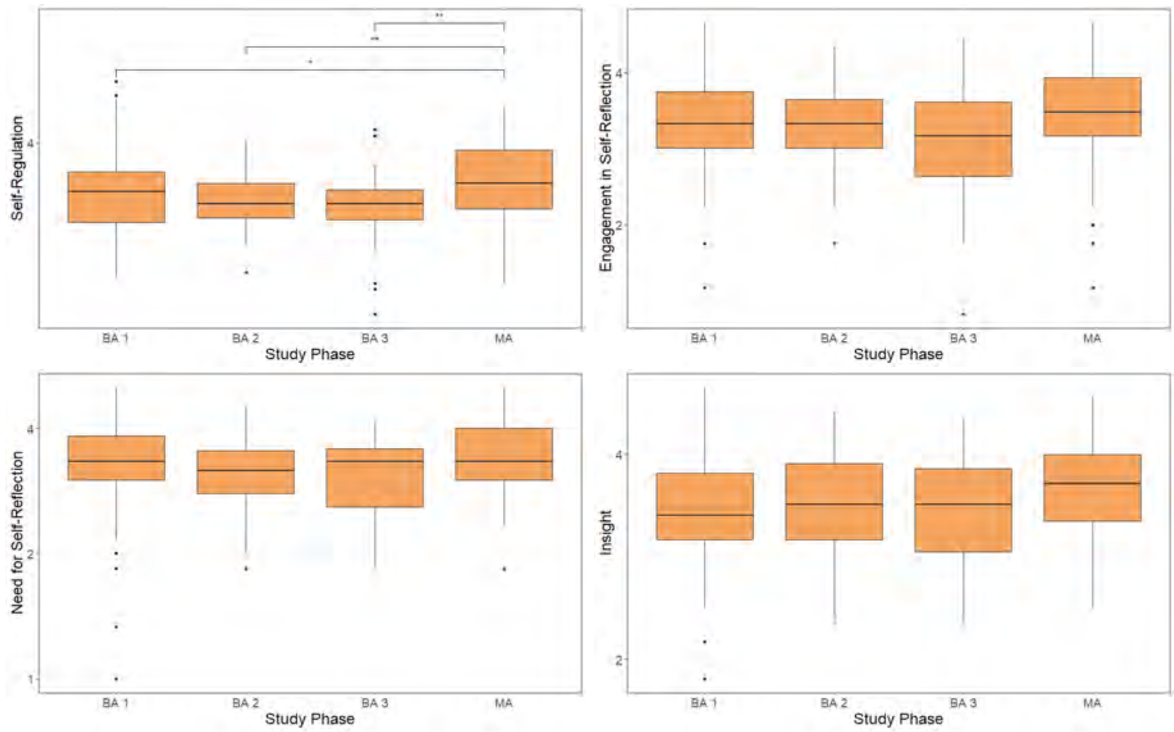

Figure 2. Comparison of scores, TSE students only. Left to right, top to bottom: Self-Regulation, Engagement in Self-Reflection, Need for Self-Reflection, Insight.

When looking at all study phases combined, as in Table 2, the same tendencies can be observed. Their overall *Self-regulation* scores are not significantly different, but the underlying factors beg to differ. Females' *Engagement in self-reflection* is somewhat higher than males' ($d = 0.44$, $p < .001$), and they show a slightly higher perceived need for it ($d = 0.22$, $p = .04$). In contrast, females report less *Insight* than males ($d = 0.43$, $p < .001$).

DISCUSSION

To allow for a meaningful interpretation of these SRIS scores, they were compared to the results reported by Grant et al. (2002), Roberts and Stark (2008) and Naeimi et al. (2019). Their results are presented in Table 3, rescaled to the $[1, 5]$ interval. The engineers' self-reflection scores were similar to the psychology undergraduates' results reported by Grant et al. (2002), yet the former rated their insight levels higher than the psychologists did. When comparing the engineers' scores to those of medicine students, as presented by Naeimi et al. (2019) and Roberts and Stark (2008), the latter group rates themselves higher on all subscales.

In general, Engineering Technology students' *Need for self-reflection* appears to increase slightly towards their senior year, whereas no significant differences could be found in terms of *Engagement in self-reflection*, *Insight* or *Self-regulation* as a whole. This is largely in line with findings from Roberts and Stark (2008), who report no differences in any subscale across cohorts. This paper's data analysis, however, contrasts theirs with a higher need for reflection in students' senior year. This does not necessarily imply that individual students experience a growth, as

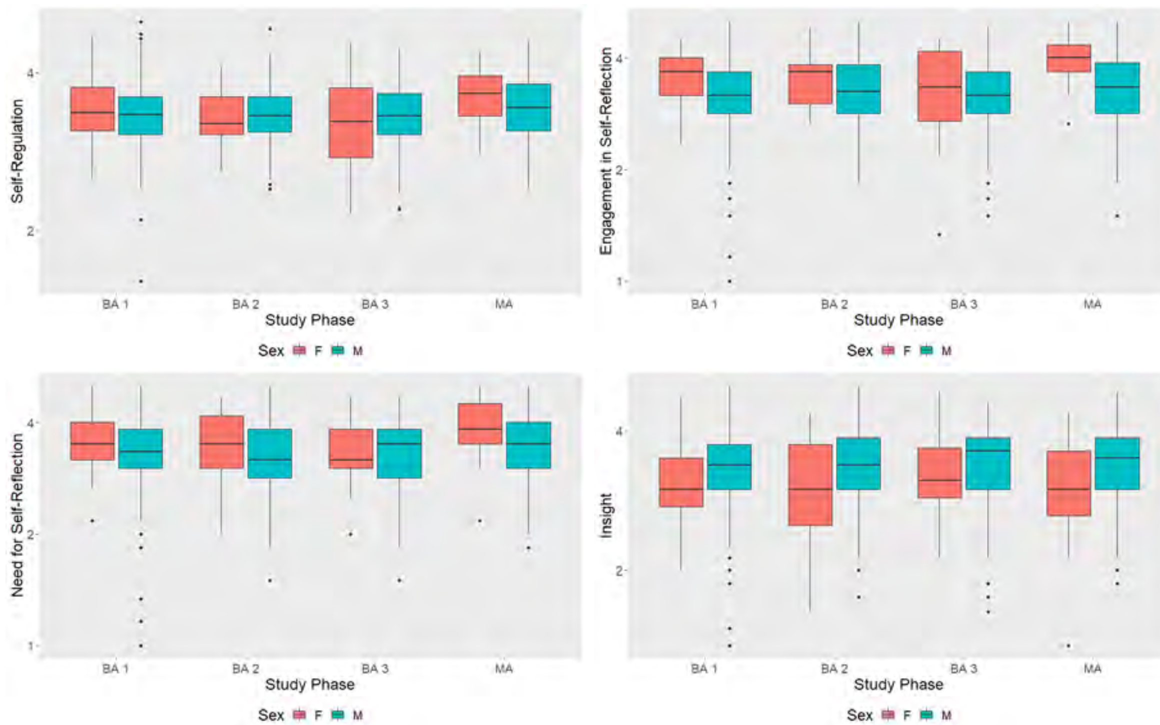

Figure 3. Comparison of scores per study phase, grouped by students' sex. Red: females, turquoise: males. Left to right, top to bottom: Self-Regulation, Engagement in Self-Reflection, Need for Self-Reflection, Insight.

these differences may also be caused by differences in student population composition. To confirm an actual individual growth, it is necessary to collect and analyze longitudinal data.

The picture gets more interesting when we look at the details underneath. Students' educational background, for example, appears to influence self-regulation levels. Students with a more general background (GSE) do not show too much progression in *Self-regulation* across cohorts, whereas students with a more technical background (TSE) possess significantly higher levels in their senior year. A possible explanation for this may lie in the secondary education institution's focus (or lack thereof) on self-regulation competencies. When looking up the learning goals for mathematics as defined on Onderwijsdoelen.be (n.d.), GSE students are expected to "*(...) develop self-regulation concerning the acquisition and processing of mathematical information and problem solving*". TSE students, on the other hand, should "*(...) be willing to adapt their learning process based on reflection on their used methods to solve mathematical problems and on the way they acquire and process mathematical information*". Despite these two learning goals sounding quite similar to one another, it can be noted that GSE students are more explicitly expected to develop self-regulation. It is possible that these programs pay more explicit attention to self-regulation than TSE programs do due to the way these learning goals are formulated, which may explain the former's higher levels when entering higher education and the latter's apparent growth. It would be interesting to know whether GSE students have somehow reached a ceiling level of self-regulation by the time they start their higher education studies, and that therefore there is no apparent increase in their levels over the years; or that their levels are too high to be impacted by any attention given to the skill as part of the program,

Table 3. Engineering Technology students' average SRIS scores, repeated from Table 1, compared to those found in the literature. Grant et al. (2002) only reported a score for self-reflection as a whole, i.e. for a combination of engagement in and need for it.

Study	Domain	Country	Engagement	Need	Insight
KU Leuven	Engineering	Belgium	3.33	3.41	3.35
Grant et al. (2002)	Psychology	Australia	3.40	3.40	2.66
Roberts and Stark (2008)	Medicine	UK	3.90	3.75	3.64
Naeimi et al. (2019)	Medicine	Iran	3.88	3.96	3.62

implying that if suitable interventions were implemented, they too would develop further.

When looking at male and female students separately as in Figure 3, it is clear that their self-report scores are differently distributed. In the case of *Engagement in self-reflection*, for example, males' scores appear to vary little over the years, whereas females' seem to rise in their senior year. Some trends can be observed, such as that females generally have a higher level of need for, and engagement in, reflection. This is in contrast to the findings of Roberts and Stark (2008) and Grant et al. (2002), who report no statistical differences between males and females in terms of self-reflection. On the other hand, females' reported insight levels are found to be lower than males', confirming Roberts and Stark (2008)'s earlier work. Grant et al. (2002), however, reported an absence of significant differences between males and females, also in terms of insight. As males and females score differently on all three subscales, it makes sense to remain cautious and to treat them as separate groups in future work.

Self-report instruments have their limitations (Paulhus, 1984) (Crandall, 1973) and it is unclear to what extent this influences the results. As these scores are based on a self-report, one has to be cautious to conclude that, for example, females engage more in self-reflection or possess less insight; they may just be prone to under- or overestimating themselves. Self-report scores are ideally accompanied by qualitative results that help make sense of them.

CONCLUSIONS AND FUTURE WORK

This paper presents baseline results for Flemish Engineering Technology students' self-regulation levels, both per underlying factor and as a whole. In general, master students experience a slightly greater need for self-reflection than bachelor students do. Discerning between student profiles leads to a few more insights.

Educational background plays a part in Engineering Technology students' development of self-regulation at KU Leuven. There were no significant differences in GSE students' population scores over the years, yet TSE students' self-regulation showed a clear increase towards the end of their study program. Male and female students also differ in their self-report scores, with females generally ranking their insight lower than male students do. Females, however, report to spend more time in self-reflection and feel a greater need to do so. In consequence, males' and females' self-regulation levels are comparable as a whole, but caused by a different distribution of scores on the underlying factors.

To measure a possible growth in engineering students' self-regulation levels, the SRIS survey will be administered to the same cohorts of students every year for four years. These results are the first measurement and will be used for longitudinal analysis with future data. They will also be used for future work involving the design, development, and piloting of interventions focusing on self-regulation. This baseline will be used in combination with qualitative methods to allow for a correct and reliable measurement of their effectiveness in higher engineering education.

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BIOGRAPHICAL INFORMATION

Ir. Shan Tuyaerts joined the ETHER research group as a PhD candidate in October 2022. She combines her background in Engineering Science (Computer Science) with her passion for education in the topic of engineering education. In the context of the REFL³ECT project, she researches lifelong learning for engineers, with a focus on self-regulation.

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Dr. ing. Lynn Van den Broeck holds a master's degree in Chemical Engineering Technology and a PhD in Engineering Education Research. Her PhD research focused on improving the guidance and support of transfer students in Engineering via the development of a validated diagnostic test and effective interventions. Her research interests focus on study guidance, effectiveness and efficiency of educational interventions, LLL and professional competencies, and feedback.

Prof. dr. Greet Langie is a professor at the Faculty of Engineering Technology, KU Leuven. She's a physicist by training and the chair of the research group focusing on Engineering Education Research on Campus De Nayer. She performs research in various fields related to the transition from secondary education to higher education and from higher education to professional life. She was the vice dean of education of the Faculty of Engineering Technology at KU Leuven from 2012 until 2020 and is now the vice chair of education of Campus De Nayer.

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LIFELONG LEARNING AS EXPLICIT PART OF ENGINEERING PROGRAMMES: A CASE STUDY

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ABSTRACT

Today's workplace is characterized by continuous technological advancements and shifting requirements in the labour market, increasing the need for lifelong learning (LLL) competencies for engineers. By focusing on LLL in the curriculum, engineering students are made aware of the importance of LLL competencies, preparing them for their future as an engineer in the working field. To carefully and concretely formulate learning outcomes is considered good practice in education, especially for professional competencies. In this study, the learning outcomes of three engineering specialisation tracks were analysed. Firstly, the learning outcomes are mapped against five LLL competencies, namely (1) self-monitoring, (2) locating and scrutinizing information, (3) self-reflection, (4) creating a learning plan and (5) willingness, motivation, and curiosity to learn. Secondly, heat maps were created to visualise cold and hotspots of learning outcomes on LLL throughout the engineering programme. In line with the general view that professional competencies are only occasionally integrated into learning outcomes, findings show that LLL competencies are not fully embedded in the learning outcomes. Two out of five LLL competencies, namely creating a learning plan and willingness, motivation, and curiosity to learn, are not present in any of the learning outcomes. Additionally, hotspots of learning outcomes on LLL are limited to the first and/or final year of the programme. This case study is a first step towards enhancing our knowledge on how LLL is implemented in learning outcomes. The selected mapping technique and heat map visualisation can be used in future work to evaluate study programmes and to inform curriculum development.

KEYWORDS

Lifelong Learning, Engineering Education, Curriculum, Competencies, Learning outcomes, Standards: 2,12

INTRODUCTION

Lifelong learning (LLL) in the workplace has become increasingly more important during the last century and its importance will only increase further (Mourtos, 2003; Uden & Dix, 2004). Changing worldviews and technological advancements require employees to continuously update their knowledge, skills and attitudes (Uden & Dix, 2004). In a field like engineering, where technology and science play a central part, LLL is even more vital (Martínez-Mediano & Lord, 2012). By the time students graduate, parts of the course content will be dated or incomplete (Uden & Dix, 2004). Today, higher education institutions are faced with the challenge of preparing engineering students for a life full of learning (Cheah et al., 2019; Martínez-Mediano & Lord, 2012; Uden & Dix, 2004).

Lifelong Learning and Higher Education

Higher education curricula need to be developed in accordance with the society and workplace engineering students end up in (Peat et al., 2005; Walkington, 2002). Considering the importance of LLL, higher education institutions have a responsibility to prepare engineering students for LLL in the workplace (Cheah et al., 2019; Martínez-Mediano & Lord, 2012; Uden & Dix, 2004).

Traditionally, engineering curricula have focused on the transfer of typical engineering competencies, such as technological and scientific knowledge. Today, the core function of education is no longer restricted to the transfer of field-specific knowledge. Professional competencies and more specifically LLL receive more attention in the curriculum and are increasingly becoming a central part of education (Kovacs et al., 2020; Martínez-Mediano & Lord, 2012; Yap & Tan, 2022).

Learning Outcomes

The first step in implementing LLL in an engineering programme, should be to include learning outcomes containing LLL competencies. Learning outcomes are the explicit written goals for each course within a programme. They indicate what the student should know and be able to do after completing the course (Adam, 2008). Learning outcomes support the recent focus on student-centred education as opposed to teacher-centred education (Fitzpatrick et al., 2009; Kennedy, 2006). In the latter education is structured in terms of which practices a teacher is going to use and what content they will be teaching. Learning outcomes follow a student-centred approach by focusing on outcomes for students.

Historically, learning outcomes were slowly introduced during the Bologna process (Gaebel, M., Zhang, T., Bunescu, L., & Stoeber, 2018). Initially, learning outcomes were mentioned sporadically in ministerial communiqués on mobility and cooperation in tertiary education, such as the Berlin communiqué of 2003. Learning outcomes were first introduced as mere tools to internationally compare educational programs, but later they became central to the student-centred and outcome-based philosophy of the Bologna reforms (Adam, 2008). Today, learning outcomes are a standard in all universities in the European Union (Kennedy, 2006).

Establishing clear learning outcomes has a positive impact on education for both lecturers and students (see Kennedy, 2006 for an overview). For lecturers, the learning outcomes provide a clear framework to guide curriculum and course design (Adam, 2004, 2008; Jenkins, Alan & Unwin, 2001). For students, they create more accurate expectations of the content of courses (Adam, 2008; Fitzpatrick et al., 2009; Jenkins, Alan & Unwin, 2001). The student-centred nature of learning outcomes also puts students at the centre of their learning process which can increase motivation, responsibility and enthusiasm for learning (Adam, 2004; Maher, 2004). In the context of international education, which was the original focus of the Bologna reforms (Gaebel, M., Zhang, T., Bunescu, L., & Stoeber, 2018), learning outcomes also increase the comparability of course content between universities (Adam, 2004). Taken together, learning outcomes and the associated view on education are expected to improve the learning process.

One important caveat is that learning outcomes do not equal educational practice and a discrepancy between the two is possible. Firstly, not all learning outcomes are implemented in educational practice. Lecturers are obligated to write learning outcomes, but the degree to which they stick to these outcomes is not always monitored (Kovacs et al., 2020; Maher, 2004). Secondly, not all educational practices are always translated to learning outcomes (Armstrong & Niewoehner, 2008). Lecturers might trigger a wide range of competencies during the lectures, the so-called hidden curriculum (Orón Semper & Blasco, 2018), but only the competencies they deem to be important are in the formal learning outcomes. Learning outcomes thus offer an insight into what goes on in a study programme but are almost never a perfect reflection.

The Current Study

The current case study aims to assess the presence of LLL competencies in the learning outcomes of an English-speaking engineering technology programme at a European university. The research questions are the following:

1. To what extent are LLL competencies present in the learning outcomes of an engineering programme?
2. How does the presence of LLL competencies in learning outcomes differ within and between specialization tracks?

These research questions are answered by mapping learning outcomes in the engineering technology programme against a predefined set of LLL competencies. The presence of LLL competencies in the learning outcomes (RQ1) and differences within and between programmes (RQ2) are visualised using heat maps.

Based on a systematic literature review on competency measurement methods in engineering education (Cruz et al., 2020a), the following LLL competencies are included: (1) self-monitoring, (2) locating and scrutinizing information, (3) self-reflection, (4) creating a learning plan and (5) willingness, motivation and curiosity to learn.

1. Self-monitoring is to monitor the learning process by periodically assessing performance and progression (Cruz et al., 2020a).
2. Locating and scrutinizing information is a LLL competency that includes independently searching, identifying and interpreting new information or knowledge (Cruz et al., 2020a).
3. Self-reflection is the inspection and evaluation of one's thoughts, feelings and behaviour (Grant et al., 2002).
4. Creating a learning plan means making a plan to prepare for future learning activities by identifying learning goals and planning steps to reach them (Cruz et al., 2020a).
5. The willingness, motivation, and curiosity to learn is a collection of attitudes towards learning that proceed and guide the learning process. The willingness to learn is an impulse or desire to acquire new competencies (Hotifah et al., 2020). The motivation to learn is an internal state that serves to activate learning behaviour and give it direction (Huitt, 2011). The motivation to learn as a LLL competency is mostly related to intrinsic motivation as opposed to extrinsic motivation. The curiosity to learn is the desire to learn new information, experiences or knowledge (Grossnickle, 2016).

METHOD

This case study reviews the learning outcomes of an Engineering Technology programme with three specialisation tracks, namely Electronics engineering, Electromechanical engineering, and Chemical engineering. The programme exists, regardless of the track, of three bachelor years and one master year, with each year consisting of 60 ECTS (European Credit Transfer and Accumulation System) and the full programme consisting of 240 ECTS (4 times 60 ECTS). The first bachelor year is the same for all tracks and the second bachelor year also largely overlaps between the tracks. The third bachelor and the master year are predominantly separate.

For each track, a list of courses with accompanying learning outcomes is available on the university website. Additionally, an ECTS credit is assigned to each course. The complete study programmes were extracted which includes all courses in each year of the track with the accompanying learning outcomes and ECTS of each course. The number of learning outcomes in het total programme differ slightly between the specialization tracks ($N_{\text{Electronics engineering}}$ = 1,635; $N_{\text{Electromechanical engineering}}$ = 1,702; $N_{\text{Chemical engineering}}$ = 1,667).

In the mapping stage, each individual learning outcome is mapped against the five LLL competencies as defined by Cruz et al. (2020), namely (1) self-monitoring, (2) locating and scrutinizing information, (3) self-reflection, (4) creating a learning plan and (5) willingness, motivation and curiosity to learn. The mapping is completed in a flexible manner, meaning that different wordings or synonyms can be used to describe the LLL competencies. Specific terminology that applied to each of the competencies was agreed upon so that consistency in the mapping process was achieved. Table 1 provides some examples of different wordings that were identified as acceptable for each competency.

A learning outcome is ascribed a mapping score of 0 or 1 depending on the absence or presence of a certain LLL competency. A learning outcome can have a 0 mapping score for each of the LLL competencies or multiple 1 mapping scores. Then, the mapping scores are summarized on both year-level and programme-level for each LLL competency. These mapping scores indicate the number of learning outcomes in one year of the programme (for example the first bachelor) or the full programme that include the LLL competencies.

However, these mapping scores do not take the course load into account. A learning outcome in a 20 ECTS course will possibly have a larger presence in the curriculum than in a 3 ECTS course. Based on this assumption, the mapping scores are also multiplied by the ECTS of the respective course before summarizing to create ECTS weighted mapping scores. Both the unweighted mapping scores and the ECTS weighted mapping scores are included in the analysis.

Finally, the weighted and unweighted mapping scores are visualised using heatmaps. In this visualisation, the colour of a cell varies based on the mapping scores creating hot and cold spots. The colour scheme was defined using a colour scale generator (An, 2020). The middle point of the scale was set at a bright orange (#FC7419) with a light yellow at the lower end of the scale (luminosity: 87%, hue angle: - 25º, saturation: 14%) and a dark red at the higher end of the scale (luminosity: 59%, hue angle: 25º, saturation: 14%).

Table 1. LLL competency example learning outcomes

LLL competency	Example learning outcomes
Self-reflection	1. (…) think critically, rationally, and logically coherently about the role and responsibilities of engineers (…) 2. (…) explain their responsibility and their call as engineers in the society of the future
Locating and scrutinizing information	1. (…) find and summarize relevant information on recent biomedical research 2. (…) collect, critically process, and interpret new information and knowledge
Self-monitoring	1. (…) solve problems, can respect deadlines, be flexible and shows perseverance 2. (…) can divide the work in his lab team and can take his responsibility in preparation, execution, and reporting

Note. Example learning outcomes of 'Creating a learning plan' and 'Willingness, motivation and curiosity to learn' are not included because none were found.

RESULTS

Table 2 shows the presence of the LLL competencies in each of the three specialization tracks. Both the competencies 'Creating a learning plan' and 'Willingness, motivation and curiosity to learn' are not included in any of the learning outcomes. From the other competencies, 'Self-reflection' ($\bar{x}$ = 5 (21)) is included the least. 'Self-monitoring' ($\bar{x}$ = 6.67 (45)) is included slightly more and 'Locating and scrutinizing information' ($\bar{x}$ = 10.33 (77.33)) the most. When comparing between programmes, minimal differences can be recognized.

The presence of LLL competencies can be assessed across the years of the programme. Table 3 visualises this using the unweighted mapping scores showing hotspots of the competencies within each track. 'Self-monitoring' is the most spread out of the three competencies with learning outcomes included in bachelor courses such as 'Dynamics and energy' and 'Engineering experience' as well as in the master's thesis. 'Locating and scrutinizing information' is included in the first bachelor as well as in the final years. 'Locating and scrutinizing information' is also included in different courses such as 'Chemistry', 'Trends and innovations in the biomedical sector' and 'Master's thesis'. Hotspots of self-reflection are present in the bachelor years in the courses 'Enterprises and ethics' and 'Religions'.

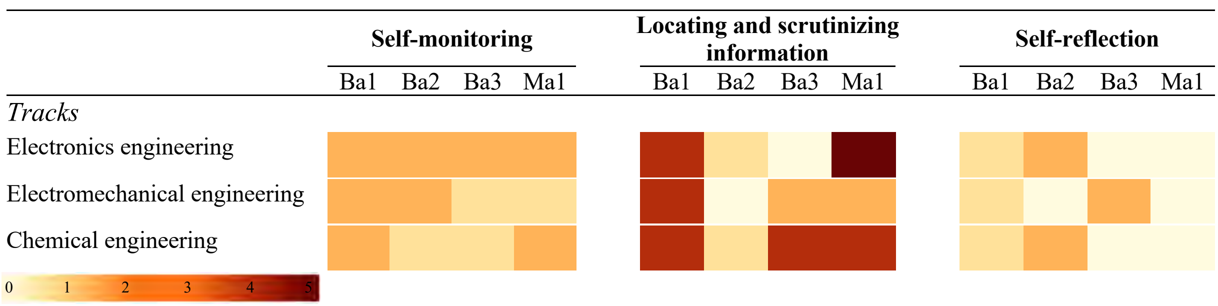
The heat maps in Table 4 contain the ECTS weighted mapping scores, taking course load into account. For 'Self-monitoring' the hotspots shift towards the final master year. This is in contrast with the more spread-out picture in Table 3. For 'Locating and scrutinizing information' the heat map in Table 4 shows comparable results. Both shifts can be explained by the 20 ECTS weight of the master's thesis. 'Self-reflection' is now slightly more emphasized in the first bachelor year.

Table 2. Mapping Scores on Programme-level

	Self-monitoring	Locating and scrutinizing information	Self-reflection	Creating a learning plan	Willingness, motivation, and curiosity to learn
Tracks ($\bar{x}$)	6.7 (45)	10.3 (77.3)	5 (21)	0 (0)	0 (0)
Electronics engineering	8 (40)	10 (73)	5 (21)	0 (0)	0 (0)
Electromechanical engineering	6 (41)	8 (79)	5 (21)	0 (0)	0 (0)
Chemical engineering	6 (54)	13 (80)	5 (21)	0 (0)	0 (0)

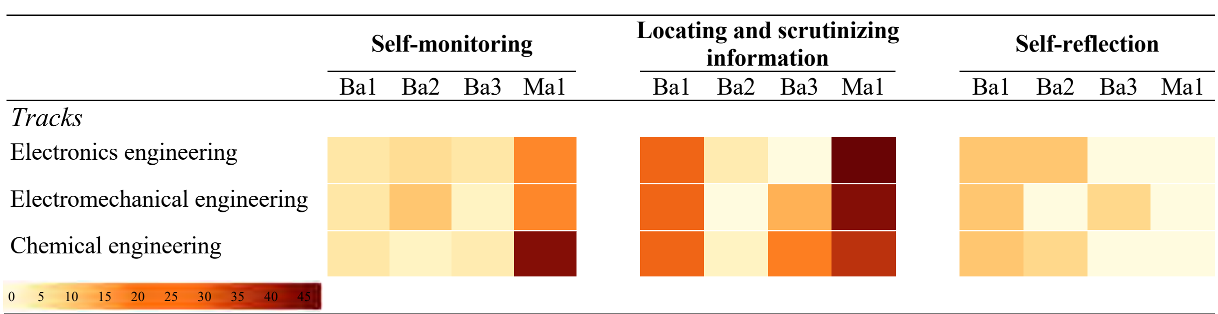
Note. Unweighted mapping scores with the corresponding ECTS weighted mapping scores in brackets.

Table 3. Heat map unweighted mapping scores



Note. 'Creating a learning plan' and 'willingness, motivation and curiosity to learn' are not included in the heat maps because they are not present in any of the learning outcomes. Ba1, Ba2 and Ba3 refer to the first, second and third bachelor year and Ma1 is the master year.

Table 4. Heat map ECTS weighted mapping scores



Note. 'Creating a learning plan' and 'willingness, motivation and curiosity to learn' are not included in the heat maps because they are not present in any of the learning outcomes. Ba1, Ba2 and Ba3 refer to the first, second and third bachelor year and Ma1 is the master year.

DISCUSSION

This case study examines the presence of LLL competencies in the learning outcomes of an engineering technology programme. Firstly, the learning outcomes are mapped against five LLL competencies, namely (1) self-monitoring, (2) locating and scrutinizing information, (3) self-reflection, (4) creating a learning plan and (5) willingness, motivation, and curiosity to learn. The LLL competency 'Locating and scrutinizing information' in the chemical engineering track has the highest mapping score (N = 13) on the programme-level. However, this means that out of the 1,667 learning outcomes in the chemical engineering track, less than 1% focuses on this LLL competency. The 'hotspots' that are shown in the heat maps thus only reflect a small number of learning outcomes in comparison with the total number of learning outcomes. Additionally, two out of five LLL competencies, 'creating a learning plan' and 'willingness, motivation and curiosity to learn' were not detected in the learning outcomes of the programme. A benchmark or reference point that determines the number of learning outcomes that should be devoted to LLL does not exist which makes it difficult to draw strong conclusions. However, it can be concluded that LLL competencies are not fully embedded in the learning outcomes. Considering the importance of LLL (Martínez-Mediano & Lord, 2012; Uden & Dix, 2004) and the responsibility of higher education institutions in teaching LLL competencies (Cheah et al., 2019; Martínez-Mediano & Lord, 2012; Uden & Dix, 2004), the further implementation of LLL competencies in learning outcomes is something to devote more attention to.

When looking at the courses that include LLL competencies in their learning outcomes, several of those courses are not part of the core engineering curriculum. In particular, self-reflection is included exclusively in the courses 'Enterprises and ethics' and 'Religions'. This is in line with the finding of Kovacs et al. (2020) on professional competencies in an engineering programme. When Social and Human sciences courses were excluded from their analysis, the number of learning outcomes on professional competencies reduced drastically. They argue that along with the positive impact of teaching professional competencies to engineering students there can be an additional negative impact on the way students perceive professional competencies. By not including professional competencies in the core curriculum, the idea of professional competencies being a by-product of engineering education and subordinate to the typical engineering competencies is reinforced.

Related to the second research question, the heat maps visualise differences between and within the tracks. The differences between the tracks are minimal with a similar distribution of LLL competencies across the tracks. For the first years of the tracks this was expected considering the joint first year and mostly joint second year of the bachelor. In the final bachelor and master year no differences between the tracks stand out. However, within the programme clear changes can be found. Learning outcomes on self-reflection are included exclusively in the bachelor year with a stronger presence in the first years. 'Locating and scrutinizing information' is emphasized in both the first and last year of the programme. Finally, self-monitoring learning outcomes are more spread out and when taking the ECTS weights into account hotspots of 'Self-monitoring' are found in the master year. In general, it can be concluded that learning outcomes on LLL competencies are more likely to be included in the learning outcomes of the first and final year of the programme.

For the typical engineering competencies, it is considered self-evident to develop competencies over the course of the programme. For example, all knowledge an engineer needs on mathematics will be divided over a couple of courses. Throughout the programme, engineering students follow these mathematics courses building on the knowledge from the previous course. However, this careful development is in sharp contrast with the sporadic implementation of LLL competencies in learning outcomes. The heat maps demonstrate the lack of competency development over the course of the programme for LLL competencies. To solve this issue, a programme wide initiative is necessary. Since the introduction of learning outcomes, authors have been pointing out the need for a top-down strategy for implementing learning outcomes (Armstrong & Niewoehner, 2008; Walkington, 2002). However, today lecturers are responsible for both formulating and implementing professional and LLL competencies in the learning outcomes of their courses. Walkington (2002) argued that both strategies are necessary, a top-down strategic plan that takes the whole programme into account as well as bottom-up input from lecturers and educational practitioners. A top-down strategy for higher education institutions to implement LLL competencies can support the step-by-step and progressive development throughout the programme.

It is important to point out that this case study only provides one perspective on the implementation of LLL competencies in the programmes. Learning outcomes are not always a perfect representation of what goes on in the lecture hall and in the minds of students (Armstrong & Niewoehner, 2008; Maher, 2004; Orón Semper & Blasco, 2018). Educational practice can be much richer than these written statements. A lecturer might attach great importance to self-monitoring and lets students prepare the material before class. In the learning outcomes, it is likely that only content-related statements are included. This is especially plausible for professional competencies since they are often considered to be a by-product of education and part of the hidden curriculum (Orón Semper & Blasco, 2018). Further, what students learn in a programme also goes beyond what they learn in their classes. The competency of creating a learning plan for example can also be supported by study guidance or faculty-provided resources (Wingate & London, 2007). The degree to which the results of the heat maps resonate with the experience of both students and lecturers needs to be explored in future research. Combining the perspectives of students and lecturers with learning outcome analysis can further inform institutional action and strategy.

Although learning outcomes are not identical to educational practice, they are an important aspect of it and deserve careful attention. Students often read them before the start of the course, which can influence their expectations and the way they look at the course and education by extension (Adam, 2008; Fitzpatrick et al., 2009; Jenkins, Alan & Unwin, 2001). For lecturers, the learning outcomes are expected to guide the way they teach a course and partially reflect their perspective on the course (Adam, 2004, 2008; Jenkins, Alan & Unwin, 2001). Considering the importance of LLL for engineers, the implementation of LLL in higher education deserves careful attention and this should be reflected in the learning outcomes.

CONCLUSION

This case study shows the intensity with which lifelong learning competencies are currently implemented in the learning outcomes of an engineering technology programme. LLL competencies are currently not fully embedded in the learning outcomes and are mostly limited to the first and final year of the programme. This study is a first step towards enhancing our understanding of how lifelong learning is implemented in education. The mapping technique and heat maps provide a tool to evaluate the learning outcomes of study programmes. This method indicates hot and coldspots in the curriculum which can be used to inform curriculum development. The degree to which the results resonate with the experience of both students and lecturers needs to be explored in future research. The combination of heat maps and the perspectives of lecturers and students can serve as a basis to inform the further implementation of lifelong learning competencies.

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BIOGRAPHICAL INFORMATION

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ASSESSMENT AND FEEDBACK ACROSS VARIOUS OUTCOMES IN PROJECT-COURSES: A DEPARTMENT-WIDE STUDY

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ABSTRACT

Project-based learning plays a central part in many study programs in technology and engineering and have demonstrated success both in motivating students and promoting effective learning both of technical engineering skills and more generic skills related to teamwork and collaboration. Yet, especially the assessment of the more generic skills has been pointed out as challenging in research literature. It is therefore interesting to know how teachers think about feedback and assessment in their project courses, and whether they view any challenges in balancing the assessment of various learning outcomes pursued by project courses. In this study, 12 teachers from the same university department were interviewed. The purpose was to investigate what learning outcomes are pursued in their project courses, what approaches are used for assessment and feedback, and how do assessment and feedback practices prioritize between different learning outcomes? Findings indicate that there is more weight on the technical, engineering-oriented outcomes than the interpersonal communication outcomes, although this varies among the courses. Some of the courses emphasize reflection about the team process and how the members' communicative skills developed through the project, though there is no thorough assessment whether these skills improved during the project. This is in line with findings from international studies, indicating that interpersonal skills like collaboration are very hard to assess.

KEYWORDS

Project-based learning, Computing, Assessment, Feedback, Standards: 2, 5, 7, 8, 11

INTRODUCTION

Project-based learning (PjBL) plays a central part in many study programs in technology and engineering. Project courses provide a good arena for students to conceive, design, and implement engineering artefacts (Pee & Leong, 2005), and also to consider overarching issues related to ethics and sustainability (Bolstad, Lundheim, Strømberg, Orlandic, & Zimmermann, 2021). Not the least, projects give opportunity for so-called *dual use of time*, pursuing learning outcomes related to employability skills such as communication and collaboration while still achieving disciplinary skills previously pursued in more lecture-based courses (Edström, Gunnarsson, & Gustafsson, 2007; Leslie, Gorman, & Junaid, 2021; Winberg et al., 2020). Indeed, empirical studies have indicated that a switch to PjBL does not cause a loss of content knowledge, rather an increase (Ralph, 2016; Chen & Yang, 2019). At the same time, assessment in project courses is challenging. Guo et al. (2020) observed that project-courses have up to four different types of outcomes: cognitive, affective, behavioral, and artefact (related to the developed product) but that many of these outcomes tend to be assessed just by student self-reporting of perceived learning rather than any measurement of improvement from start to end of the course. Especially for collaboration and communication skills, one reason could be that they are hard to measure (Scoular, 2021), and teachers in engineering departments tend to be experts in the disciplinary content knowledge, not in more generic skills.

The Department of Computer Science at the NTNU is involved as a main contributor of courses in a dozen different degree programs, each having several project courses. Hence, there is a lot of variation in these project courses, both regarding the student group, and various aspects of the project course design (Sindre, Giannakos, Krogstie, Munkvold, & Aalberg, 2018). We wanted to look at the department's full portfolio of project courses in the light of the following research questions: **(1) What learning outcomes are pursued in the project courses? (2) What approaches do the project courses use for assessment and feedback? (3) What is the relative priority of the assessment and feedback practices when it comes to different learning outcomes,** such as disciplinary content knowledge (e.g., software design) versus more generic skills (e.g., communication and collaboration)?

The rest of this article is structured as follows: Section 2 presents some background on the department and its educational offerings, as well as some related research. Section 3 then explains our research method for this article, whereupon findings are presented in section 4. Finally, section 5 offers a concluding discussion on how to interpret the findings, and how feedback in project courses could be improved.

BACKGROUND AND RELATED RESEARCH

The Department of Computer Science at the NTNU, whose project courses are the target of this empirical study, is the second largest university department within the field of computing in Norway when it comes to person-years employed, and the largest in study credits produced per year. It is a main contributor of courses to the following study programs:

- Integrated 5-year master: Computer Science.
- 3-year bachelor programs: Informatics; Programming; Cybersecurity; Digital Business Development; Bachelor Engineering CS; Information Technology.
- 2-year master programs: Informatics, Applied Computer Science, Cybersecurity, Collaboration Technology, Healthcare Informatics.

Most of these programs are taught at the main NTNU campus in Trondheim, but two are taught in Gjøvik, two across campuses in multiple towns, and one fully online for remote students. In addition, the Master Healthcare Informatics is an experience-based continuing education program, students mainly working remotely but also participating in intensive gatherings in Trondheim. This plurality of educational offerings stems from the fact that the department (and NTNU as a whole) has grown through several mergers, thus having a combination of more academic study programs coming from the old university, and engineering-oriented programs from former colleges in Trondheim, Gjøvik, and Ålesund. All these study programs have several project courses. As an example, Table 1 shows the course composition of the 5-year integrated master program in Computer Science, which is offered in the Trondheim campus. Abbreviations in the table: CS1 is intro programming in Python, OO prog is object-oriented programming (Java), HCI = Human-Computer Interaction, and AI is Artificial Intelligence.

Table 1. 5-year integrated master, Computer Science at NTNU

Semester	Courses			
10	Master thesis			
9	Elective	Thesis prep theory	Master thesis pre-project	
8	Elective	Elective	Elective	Interdisc. proj
7	Elective	Elective	Customer-driven project	
6	Physics	Tech management	Elective	Security
5	Calculus 4	Elective	Intro to AI	Prog lang
4	Communication tech	Operating systems	Databases	Software eng
3	Statistics	Computer fundam.	Algorithms	Project 1
2	Calculus3	Electronics	HCI	OO prog
1	Calculus1	Discrete math	Philosophy	CS1

The third study year (semesters 5 and 6) may seem void of project courses, though some of the electives available typically include project-work counting for something like 40% of the grade. Several of the project courses shown in the figure have been analyzed in previous research. The project in the 7th semester has a long tradition, as 20 years of experience was reported already in (Andersen, Conradi, Krogstie, Sindre, & Sølvberg, 1994). The 4th semester project has been discussed in (Dingsøyr, 2022; Kolås & Munkvold, 2017; Sindre, Stalhane, Brataas, & Conradi, 2003), and the 8th semester interdisciplinary project for instance in (Jaccheri & Sindre, 2007). Project courses in the department outside the study program shown in Table 1 have also been the topic of research. For instance, Hjelsvold and Mishra (2019) report on experiences from project courses in global software engineering and open-source software engineering in the Master of Applied Computer Science in the Gjøvik campus. Rouhani et al. (2021) discuss the usage of project-based learning in a programming course for in-service teachers. (Krogstie, 2010) discusses the usage of collaboration tools, in particular in a project course in the bachelor Informatics program. However, these papers have not focused specifically on feedback in the project courses, except for (Dingsøyr, 2022) whose study evaluated an intervention for improved feedback during the 4th semester software engineering project. Key recommendations were the importance of training the teaching assistants involved in feedback, and of timeliness and fairness. With 500 students taking that project course, (Dingsøyr, 2022) also contained advice on how to deal with such scale.

Feedback in project-based learning has also been a topic of international research. For instance, Palmer and Hall (2011) find that students considered the feedback during the project very helpful in making progress. Frank and Barzilai (2004) present an approach based on eight guidelines for continuous formative feedback in a project course, finding that students found the approach useful in several different ways. Cook et al. (2019) in particular discuss student peer feedback during projects, finding that the quality of peer feedback can vary a lot, but can be boosted by training and by the teaching staff providing guiding questions that the students could consider during the peer feedback.

RESEARCH METHOD

It was chosen to exclude some project-like courses from the research reported in this paper. Courses where a project only was a minor part (less than 2.5 ECTS credits) were not considered. Moreover, we excluded research thesis courses. In Table 1, specifically, the Master thesis and Master thesis pre-project were deemed outside our scope of interest for two reasons: (i) in these courses, students are distributed among all professors in the department, receiving individual supervision. Hence, there is no unified approach to feedback in these courses. (ii) Many of these projects are more research-oriented than engineering-oriented, and this paper focuses on engineering-oriented projects. Hence, while a study of feedback practices in thesis supervision is clearly interesting, it would be complicated to investigate that together with feedback practices in earlier, more design-oriented projects. Similar research thesis courses in other study programs were considered outside this paper's scope for the same reasons.

Hence limiting the scope to design-oriented project courses with projects of a certain size, invitation to interviews were sent out by individual emails to 18 teachers of such courses. Of these, 12 responded positively, and were interviewed individually in the period 9-16 January. All respondents gave informed consent that the interview data could be used in the research for this paper. Each interview was performed in a semi-structured manner, with main questions directly resembling the research questions given in the Introduction, and then follow-up questions based on the initial answers. The duration was 30-60 minutes, depending on the amount of information the teacher provided. Some teachers were also involved in several relevant courses. The data material was further analyzed through a thematic analysis. This is a method for analyzing qualitative data that entails searching across a dataset to identify, analyze and report repeated patterns (Braun & Clarke, 2006).

RESULTS

Findings on RQ1: Learning outcomes pursued in project courses

Generally, the learning outcomes in the project courses have the well-known division, knowledge, skills and general competence. The majority are aimed at development and understanding, with a mix of professional knowledge and skills. For example, the students should gain practical experience in carrying out an engineering project, develop their ability to organise and carry out such projects, and be able to apply theoretical concepts and design principles in practice.

Half of the project courses in this study also involve learning outcomes aimed at more generic skills, such as communication and collaboration. Several teachers emphasized the importance of students being able to communicate subject material orally, explaining what they have done in a project and why. One of the teachers explains the importance of this as follows:

> *Unfortunately, there are many engineers today who have some trouble explaining themselves professionally. They simply cannot communicate what they have done. This is important.*

Stated learning outcomes related to collaboration vary from general descriptions, such as, for instance, that the students should have insight into project work and development processes, to slightly more detailed descriptions. In courses where teamwork is at the center, students shall be able to explain how they establish and carry out teamwork, related to different models for teamwork and team development, and they must be able to carry out and document teamwork and reflect on their own professional practice. One of the teachers elaborates:

> *We spend some time getting them (the students) to understand that teamwork is something else than traditional group work. In a group work, they sit together and distribute tasks: "You do task 1, you do task 2, and then I do task 3, and then the three of us get to do all the tasks with only a third of the work each." This is not teamwork. Teamwork is when we make use of each other's*

good and bad qualities together to bring about an interaction that gives added value, which means that we achieve something together, which we could not have achieved individually. So, the sum is greater than the sum of each individual.

Although not all the project courses involved in this study have collaboration as one of their 'official' learning outcomes as such, the value of collaboration is emphasized by most of the teachers, described as a more implicit benefit of the course. Quotes from two teachers:

Being able to do practical work in groups is very useful. Although we focus on the professional, of course. We don't have the capacity to take care of group processes etc.

Teamwork is important. But I don't think we have this as a learning outcome. Becomes a more implicit gain.

Findings on RQ2: Approaches to assessment and feedback

Most of the courses involved in this study are pure project-based courses, where the end-of-course exam has been replaced by a form of portfolio assessment, with typical parts such as report, reflection, demos, presentations, video, and product. Many of the teachers in this study indicated a purpose to create an arena for continuous student effort that provides a good basis for learning. One of the teachers describes his motivation for project-based courses as follows:

When I took over the course, it was exam-based. A very classic format for a university subject. Where the exercises were more of a ticket to sit the exam. The effort on these was below par. And this was very much reflected in how the students did on the exam. Because they weren't quite able to ... well, they had trouble with deeper reflection questions. Especially in relation to what theory means in practice. You have the theory, you apply it, but you also must reflect on it. This gives you a different view of the theory. And this is what a project course can add, the reflection loop. Now I only use group reports, not school exams. These provide completely different opportunities for students to reflect.

For most courses studied, the final report is the key submission in the portfolio. However, what this entails varies greatly between courses. For some it consists of several changed, and hopefully improved, versions of exercises, while others are made up of several projects or sub-projects. Some may include a preliminary study where the students plan their own project or survey the subject area. Others focus more on demos and presentations. For other courses again, user testing is central. Some courses also include retrospective parts, where students reflect on their own work process and possible improvements to the next part of the project. The latter is an important part of the well-known agile method Scrum that several of the teachers have implemented in their courses, a method well known also in software engineering education elsewhere (Kulmala, Luimula, & Roslöf, 2014; Paul & Behjat, 2019).

The number of exercises, projects and sub-projects included in the final reports also varies between different courses, as well as the weight of various parts in terms of scores or grades. The final reports often contain the students' academic arguments for choices made during the project, an analysis of the entire project work, or reflecting academically by linking their project to relevant theory. Several of the final reports also involve, albeit to varying degrees, a reflection note where the students reflect in teams or individually, or both, on the team's work process and the students' collaboration skills and how these have developed in the project. Most of the courses have a final grade, and the students are often assessed as a group. A small number of the courses have pass/fail on the final assessment, but several of these, however, plan to change back to letter grades. This to make it easier to bring out the nuanced differences between the students, and to reward students making a good effort over those who do not. However, others strongly argue for the use of pass/fail in project courses. The core argument is that this gives the groups a common goal, while at the same time the rush to achieve, which they believe students often experience with grades, decreases considerably. However, the requirement for passing must be at a high level. Quotation:

> *We have passed/failed. It is a proven choice. Not because this makes it easy to assess, but we want to avoid competition both internally within the group and between the groups. If it becomes talk of "I'm going to get an A, but he only deserves a C", then that doesn't make for good teamwork. Teamwork works well when the team has a common goal, which is in many ways the definition of a team. Our experience is that cooperation between students is best with the use of pass/fail, and when the requirement for a pass is relatively high.*

Common to the different variants of assessment described above is that the students receive guidance and regular feedback on their own work throughout the semester. In the smaller courses, the teachers themselves are actively involved in the guidance process and give the students feedback, while in the slightly larger courses this responsibility is given to learning assistants who are associated with the course. A central challenge here, according to several of the teachers, is the quality of the feedback from the assistants. Several of the teachers therefore spend a lot of time and resources on training and follow-up of the assistants, in order to raise the professional level of the feedback work.

Some courses have also included peer assessment as an important part of the assessment practice, where the students are actively involved in assessing their fellow students' work, which further increases the overall amount of feedback received and produced. One of the teachers describes his motivation for using peer assessment in this way:

> *The practice of making things from scratch is often quite far from the reality the students will face after their studies. It is often expected that they should be able to familiarize themselves with other people's projects and have an opinion about it. Not least understanding other people's codes. This is a professional competence. They need this judgment.*

Findings on RQ3: Prioritization of assessment and feedback vs. outcomes

For most courses involved in this study, the academic learning outcomes weigh the most in relation to what is assessed, both during the courses and in the final reports. Although several courses involve reflection on more generic skills such as collaboration, most of the final reports have a stronger focus on technical engineering competence. Quote from one of the teachers:

> *I would perhaps say that it is not in the reflection around the group process that the grades mainly lie. It probably isn't. Quite the contrary.*

The exceptions are the courses where the students' teamwork is central, where the guidance and feedback along the way are linked to the team itself and their collaborative process, but here, too, there is a wide spectrum from the courses that have teamwork as one of their core areas, to those that include a reflection note at the end, but leave it more up to the students to assess what should be included. Three lecturers, from three different courses, say the following:

> *No, it's no big deal, no. They can say a little about the group dynamics if they want to.*

We do not have a separate process report, like experts in teams, but the development process is part of the subject, so teamwork will be a natural topic for them to discuss in a reflection report, even if the reflection is overall mostly professional.

I think it is difficult to be absolutely sure how well the students reflect on their own collaboration skills. But they write these documents, they have written an agreement between themselves for cooperation, they evaluate their own efforts against this repeatedly, and they have to discuss this in the final report and evaluate their own efforts, so at least we see that they have reflected on this and made an effort to assess their own skills.

DISCUSSION

Interpretation of Findings

For RQ1 about learning outcomes, most of the project courses investigated were seen to have a mixture of technical, disciplinary learning outcomes and more generic learning outcomes such as interdisciplinary skills. All project courses had clearly stated disciplinary learning outcomes, while the presence of explicit interpersonal learning outcomes varied among courses. The most explicit attention to generic, interpersonal learning outcomes was found in the fully project-based courses. This is not surprising, as some of these courses have been designed as project-courses from the outset, because teachers and educational leaders have seen a need to address such outcomes in the study plan. The courses where projects only constitute a smaller part have typically started out as more old-fashioned lecture plus exercise courses with a solely disciplinary technical and theoretical focus but have gradually moved towards projects for instance to address motivational issues. Hence, considering the four types of learning outcomes that Guo et al. (2020) mention for projects, all courses could be seen to focus on cognitive outcomes (e.g., disciplinary knowledge) and artefact outcomes (e.g., quality of the designed artefact), whereas focus on behavioral and affective learning outcomes was most explicit in the courses that were fully project-based, and even here to a varying degree.

For RQ2 about approaches to assessment and feedback, the finding was that feedback on project work during the semester is provided mainly by teachers themselves in smaller classes, to a larger extent by teaching assistants in larger classes. This is understandable, as the class size differs a lot. For a class with 30 students, divided into 5-6 project teams, it may be possible for the teacher to provide detailed guidance to each team. For a class with several hundred students, this would not scale, so one would have to rely on teaching assistants and/or student peer feedback. Only two of the investigated courses had explicit setups for peer assessment and feedback, though in many of the other project courses there would be some implicit feedback between peers inside each project team. While no teachers used the exact 8 guidelines for formative feedback as proposed by Frank and Barzilai (2004) or Cook et al. (2019), many similar ideas were found concerning the importance of preparing students for teamwork up front and training students and teaching assistants on how to work with feedback.

Concerning RQ3 on the extent to which various learning outcome are assessed, the findings of this study is aligned with previous research, observing that outcomes related to disciplinary knowledge and the artefact are assessed to a much larger extent than for instance improvement in collaboration skills. As observed by Guo et al. (2020) and Scoular (2021), collaboration skills are hard to assess, so it is not surprising that this is done to a latter extent. No teachers claimed to really assess whether the students improved in this respect, although at least in some courses the students had to reflect upon their collaboration and communication.

Limitations and threats to credibility

There are several limitations to this study. One is that it investigates project courses just in one department (Computer Science) in one university (NTNU). Similar investigations elsewhere might arrive at different results concerning learning outcomes and assessment approaches. However, the department is quite large and broad, recently merged from several different smaller department with different educational cultures and geographic locations. Hence, despite being limited to just one department, there are several different academic and engineering traditions represented by the teachers and project courses studied.

Another limitation is that the study only interviewed teachers, not students. This was a deliberate choice implied by the research questions, investigating the intended learning outcomes of the courses and the learning and teaching approaches designed by the staff to achieve these outcomes – not to find out about student satisfaction or their actual learning from the courses. A follow-up study also looking at the courses from the student angle would be interesting but was considered beyond the scope of the current study. An obvious threat to validity is that teachers might consciously or unconsciously portray their courses in a more positive light than what is really mandated. Not having talked to students, this study cannot guarantee against such a weakness, but the impression was that teachers tried to be frank about their impressions about course outcomes and assessment approaches and were open in mentioning challenges they were facing with the course design and operation.

Conclusion

In line with other literature, the project courses studied here seemed to play an important role in their respective study programs, exposing students to realistic and motivating problem-solving tasks where they can link theory and practice. However, as also reported in other research, assessment of cognitive outcomes and technical design skills seem to be more mature than assessment of interpersonal skills like communication and collaboration, where the assessment approach is still very rudimentary. Hence, more educational research and innovation is needed on how to assess interpersonal skills such as collaboration and whether students improve during project courses. Still, teachers need not wait for this future research to do something. If a project course currently has no assessment of communication and collaboration skills, inclusion of some evaluation through student perception (e.g., questionnaire on whether they think their skills improved through the course, or reflection notes about how their skills developed), would be much better than nothing. Based on these perceptions – and preferably in dialogue with students – one could then consider whether it is possible to move on to assessing actual skill improvement from observed performance.

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BIOGRAPHICAL INFORMATION

Gabrielle Hansen is a senior researcher at the Excited Centre of Excellent IT Education. She holds an MSc in Psychology and a PhD degree in Pedagogy with a thesis focusing on the use of feedback in higher education. Before joining the Excited centre, she has been a researcher at the Sør-Trøndelag University College (HiST) and then at the SEED Centre for Science and Engineering Education at the NTNU, in both cases working on educational improvement interventions and the coaching of teachers during such processes. In addition to research on feedback and assessment, she has also done research on the usage of Student Response Systems in lectures.

Guttorm Sindre holds MSc and PhD degrees in Computer Science (1987, 1990). He has been a full professor at NTNU since 2003, where he served partly as Head of Dept, partly as deputy head of the CS department 2009-13. He was the leader of the Excited Centre for Excellent IT Education from 2016-21, is currently deputy leader of Excited, and study program board leader of Informatics. Sindre has teaching experience across a wide range of IT topics, from freshman introductory programming to PhD level research courses, as well as supervising several master and PhD students. His research has focused on computing education, especially how to teach introductory programming, how to mitigate threats to assessment integrity, and (before the Excited centre) on software requirements engineering and software security.

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ENGINEERING STUDENTS' SELF-REGULATION COMPETENCIES – THE RELATIONSHIP BETWEEN PERCEPTIONS AND SUMMATIVE SCORES

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ABSTRACT

There is no doubt about the importance of lifelong learning (LLL) and the responsibility that Higher Education Institutions (HEIs) hold to guide and support students in the development of LLL competencies so that each graduate is prepared for a life full of learning. With self-regulation considered as a core and malleable competency for LLL, HEIs can develop interventions to support the development of students' self-regulation competencies. It is, however, of great importance to determine the effectiveness of these interventions. Therefore this study, focusing on first and second-year engineering students, aims to gain insight in the use of and relation between two methods for measuring self-regulation competencies: a validated self-reported questionnaire on self-regulation competencies and summative scores on students' self-reflection report. Students' mean scores on the questionnaire were compared across the different summative scores (A/B/C score Critical and A/B/C score Concrete) and across the year of study programme (first year and second year) by use of ANOVA and t-tests. Few significant differences are found, but two general trends are interesting to examine further: (1) Students with the highest summative scores do not report the highest self-regulation competencies, and (2) Second-year students have overall a higher self-reported level of self-regulation competencies in comparison with first-year students and a higher percentage of second-year students obtain the highest summative score on their self-reflection. In the next steps of this research, interventions focusing on self-regulation will be developed and implemented in the curriculum. When determining the effectiveness of these interventions both measurement methods will be used. However, statistical methods will be explored to control for the Dunning-Kruger effect, seen in the self-reported questionnaires and students' possible natural growth in self-regulation competencies will be taken into account as well.

KEYWORDS

Self-regulation, lifelong learning competencies, assessment, self-reported perceptions, Standard: 11

INTRODUCTION

Lifelong learning is an explicit part of the outcomes in the European Higher Education Area (EHEA) where all university graduates must "have the learning skills to allow them to continue to study in a manner that may be largely self-directed or autonomous" (European Qualifications Framework 2005). It is therefore the responsibility of higher education to deliver graduates who are ready for lifelong learning (LLL). The latter is also confirmed by Martinez-Mediano & Lord, (2012, pg. 130): "Universities play a critical role in promoting lifelong learning through research on the topic, training of teachers to believe in the importance of lifelong learning and serving as role models and providing learning experiences which encourage students to continue learning throughout their lives."

LLL is, however, a container concept and there is no agreement yet about what lifelong learning entails precisely (Cruz et al., 2020; Qanbari Qalehsari et al., 2017). Fortunately, there is no doubt about the importance of LLL and the responsibility that Higher Education Institutions (HEIs) hold to guide and support students in the development of LLL competencies so that each graduate is prepared for a life full of learning. In their systematic review about competency methods in engineering education, Cruz et al. (2020) list the most frequently used criteria for lifelong learning competencies in engineering: self-reflection (17 studies), locating and scrutinizing information (16 studies), willingness, motivation, and curiosity to learn (11 studies), creating a learning plan (10 studies), and self-monitoring (6 studies).

Combining three of the competencies, mentioned above as creating a learning plan, self-monitoring, and self-reflection, results in the concept self-regulation. The most cited self-regulation model, according to the comparative review of Panadero (2017), is the model of Zimmerman (2000). Zimmerman (2000) distinguishes three action phases: (1) forethought, (2) performance/volitional control, and finally (3) self-reflection. Self-regulation is considered as a core competency for LLL (Clark, 2012; Naeimi et al., 2019; Schober et al., 2007) and in their study, Lord et al. (2012) even suggest that in an education context self-regulation is a proxy for LLL.

In a scoping review focusing on what HEIs can do to support students' in the development of LLL competencies, Van den Broeck et al. (2022) conclude that almost all interventions focus on a student-centred approach. This student-centred approach is implemented via a specific teaching method, or via the focus on self-regulation and reflection, or via the use of peer and self-assessments. This is not unusual, since being prepared for lifelong learning is indeed a personal matter which starts from the individual. These results also show that self-regulation is not only a core LLL competency, but also a malleable one. Consequently, HEIs can develop interventions to support the development of students' self-regulation competencies. It is, however, of paramount importance to determine if these interventions are effective and thus to gain insight in how students' self-regulation competencies can be measured.

Validated self-assessment instruments are often used to evaluate effectiveness (Khamis et al., 2020; Torres et al., 2017). Although these instruments are widely used, it is important to take into account a possible difference between a self-assessment and an external assessment (Bradley et al., 2022). This is known as the Dunning-Kruger Effect, in which low performers overestimate their competencies and high performers underestimate their competencies (Dunning, 2011).

The current study aims to determine if there is a difference between engineering students' perceived self-regulation competencies and the summative scores on their self-reflection reports. In addition, this study will analyse if there are differences between first-year and second-year engineering students. The research questions are the following:

RQ1. To which extent is a relationship present between students' summative scores on self-reflection reports and their self-reported self-regulation competencies?

RQ2. Are there differences between first-year and second-year students' self-regulation competencies, both students' summative scores on self-reflection reports and students' self-reported competencies?

METHOD

Context and participants

The present study includes first and second year engineering students from the Faculty of Engineering Technology, KU Leuven (Belgium). The Faculty of Engineering Technology implemented a complete curriculum reform, with a first cohort starting in the academic year 2020-2021. One of the focal points of this new curriculum is the increased importance of professional competencies (Langie et al., 2022). Throughout the Bachelor's programme, students follow lectures about professional competencies. Moreover, these professional competencies such as communication, leadership, project management, team dynamics, etc., are not only 'taught' in the lectures, but also 'trained' and 'evaluated' during the regular courses such as laboratories and projects. With competency development being a continuous process, where knowledge, attitudes, and skills become more and more intertwined (OECD, 2018), it is important to provide students with handholds to keep track of their progress. At one of the campuses of the Faculty of Engineering Technology it was therefore decided to implement an e-portfolio, with different self-reflection assignments, for students.

Data collection

Summative scores on self-reflection reports

The problem-based learning courses in which the data were collected spanned the full second semester (12 weeks) of the academic year 2021-2022. Apart from technical reporting, students had to contribute to peer feedback, focusing on professional competencies (e.g. communication and teamwork), and had to write self-reflection reports. The first-year students had to write three self-reflection reports, evenly spread across the semester. The second year students had to write one self-reflection report in the middle of the semester. Students received an A/B/C score on how critical and concrete they were in their self-reflection reports. For the first-year students, a weighted score for the three self-reflection reports was calculated. Students who did not submit their self-reflection reports received an NA, resulting in a score of zero on that part of the course.

Self-reported self-regulation competencies

During one of the professional competencies lectures, students were asked to fill out a survey. Students' perceptions about self-regulation competencies were measured via the Self-Reflection and Insight Scale (SRIS). This survey of (Grant et al., 2002) measures: (1) Self-reflection, which combines the two scales engagement in reflection (6 items) and need for reflection (6 items), and (2) Insight (8 items). Students answered each item on a five point Likert scale (1= Totally disagree, 5= Totally agree).

Analysis

Students' mean scores of the overall SRIS and of the three subscales were compared across the different summative scores (A/B/C score Critical and A/B/C score Concrete) and across the year of study programme (first year and second year) by use of ANOVA and t-tests. Assumptions were checked via Shapiro-Wilk tests (for normality) and Levene's tests (for equality of variances). To gauge the effect sizes, Cohen's d was calculated. A chi-square test of independence was performed to examine the relation between year of study programme and the summative scores on self-reflection reports.

RESULTS

Of the 72 first-year engineering students, a total of 49 completed the SRIS (response rate = 68%). Of these 49 students, four students did not submit their self-reflection reports, resulting in a total of 45 complete datapoints (response rate = 63%). Of the 55 second-year engineering students, a total of 39 completed the SRIS (71%). Four students did not submit their self-reflection reports, resulting in a total of 35 complete datapoints (response rate = 64%).

Table 1. First-year engineering students' self-regulation competencies

First-year			SRIS		Engagement		Need		Insight	
Reflection	Score	n (%)	M	SD	M	SD	M	SD	M	SD
Critical	A	15 (33%)	3.00	0.54	2.87	0.88	2.92	0.68	***3.15***	***0.60***
	B	21 (47%)	3.42	0.52	3.29	0.77	3.13	0.81	***3.74***	***0.52***
	C	9 (20%)	3.25	0.58	3.11	0.89	3.22	0.56	3.38	0.66
Concrete	A	15 (33%)	3.09	0.55	3.00	0.81	3.02	0.65	***3.21***	***0.59***
	B	21 (47%)	3.41	0.56	3.28	0.86	3.13	0.85	***3.71***	***0.58***
	C	9 (20%)	3.13	0.53	2.93	0.83	3.04	0.52	3.35	0.62

First-year students' self-regulation shows significant differences, with large effect sizes, on the Insight scale for both the Critical and Concrete score of students' self-reflection. Students with a Critical score B (n=21, M=3.74, SD=0.52) report significant higher Insight competencies (p=.013, Cohen's d=1.09) compared to students with a Critical score A (n=15, M=3.15, SD=0.60). The same significant difference (p= .05, Cohen's d=0.88) is found between students with a Concrete score B (n= 21, M=3.71, SD=0.58) and a Concrete score A (n=15, M=3.21, SD=0.59).

Second-year students' self-regulation shows significant differences, with large effect sizes, on the Engagement scale for the Concrete score of students' self-reflection. Students with a Concrete score A (n=15, M=3.48, SD=0.56) report significant higher Engagement competencies (p=.025, Cohen's d=1.17) compared to students with a Concrete score B (n=12, M=2.74, SD=0.77). A similar significant difference (p=.016, Cohen's d=1.24) is also found between students with a Concrete score C (n=8, M=3.77, SD=1.03) and Concrete score B.

Table 2. Second-year engineering students' self-regulation competencies

Second-year			SRIS		Engagement		Need		Insight	
Reflection	Score	n (%)	M	SD	M	SD	M	SD	M	SD
Critical	A	18 (51%)	3.22	0.43	3.14	0.76	3.19	0.68	3.3	0.69

	B	8 (23%)	3.79	0.55	3.73	0.84	3.88	0.75	3.78	0.64
	C	9 (26%)	3.42	0.69	3.2	0.97	3.35	0.93	3.64	0.81
Concrete	A	15 (43%)	3.34	0.37	***3.48***	***0.56***	3.41	0.64	3.18	0.59
	B	12 (34%)	3.23	0.46	***2.74***	***0.77***	3.15	0.74	3.67	0.77
	C	8 (23%)	3.77	0.87	**3.77**	**1.03**	3.69	1.09	3.83	0.74

No significant differences in SRIS scores were found between the first-year and second-year students, grouped by A, B, or C scores (e.g. no significant differences were found between the SRIS mean scores of first-year students with a critical score A and SRIS mean scores of second-year students with a critical score A).

The Chi² test found that the relation between year of study programme and the summative scores on self-reflection reports (A/B/C score) was not significant for both the Critical score (X^2 (2, N=80)= 1.28, p= .5263) and the Concrete score (X^2(2, N=80)=4.93, p=.0851).

DISCUSSION

A growing emphasis on and more explicit attention towards professional competencies in engineering curricula in good and much needed (Passow & Passow, 2017). This raises, however, questions about assessing all these professional competencies in an objective manner. Research about competency measurement in higher education is therefore evolving, but not yet completed (Zlatkin-Troitschanskaia et al., 2015). In their systematic review, Cruz et al. (2020), provide an overview of the existing methods to assess competencies. They discuss seven different methods: questionnaires, rubrics, tests, observations, interviews, portfolios, and reflections. Questionnaires and rubrics were used in the majority of the included studies. This study uses both a validated questionnaire (SRIS) and a rubric to assess the quality of students' self-reflection reports.

It can be hypothesized that a positive relationship exists between students' summative scores on their self-reflection reports and their self-reported self-regulation competencies, i.e. that students with a higher summative score report a higher level of mastery for these competencies. It turns out that this is not the case, as students with the highest summative score (i.e. score A) do not have the highest self-reported level of competencies.

If the aim is to assess students' self-regulation competencies after implementing interventions focusing on the development of these competencies, it will be important to select proper assessment methods. Currently, the use of the SRIS is questionable, since the Dunning-Kruger effect is present. An example is shown in Figure 1, which represents second-year students' mean score on Engagement for the three summative Concrete scores on their self-reflection reports. The low achievers, i.e. students who received a Concrete score C, report the highest level of self-regulation competencies. The high achievers, i.e. students with a Concrete score A, report higher level of self-regulation competencies than the moderate achievers, i.e. students with a Concrete score B, but still lower than the ones with a Concrete score C.

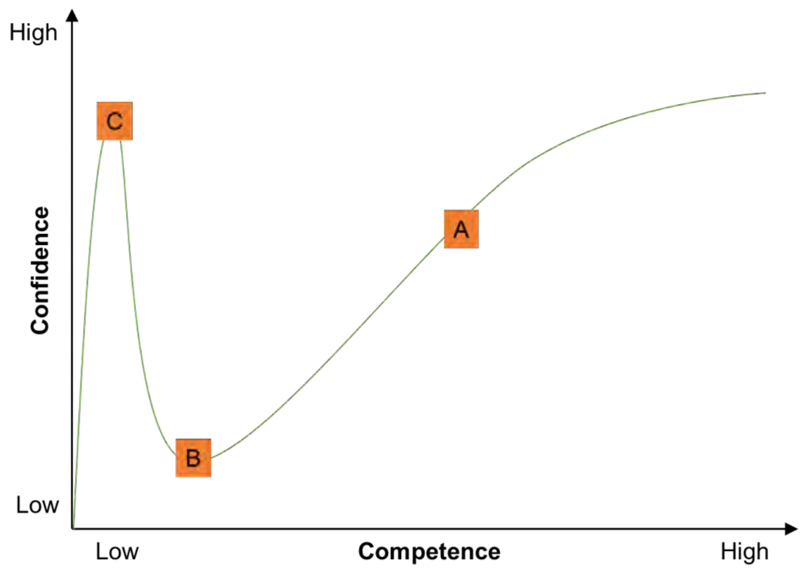

Figure 1. Dunning-Kruger effect: Second-year students' mean scores on the Engagement scale & self-reflection Concrete scores

Kruger & Dunning (1999) stated that the competencies required to achieve a particular competence level are the same competencies needed for an accurate assessment of that specific competence. To tackle this, it would be interesting to explore which statistical methods can be used to control for this effect (Gignac & Zajenkowski, 2020).

With competency development being a continuous process (OECD, 2018), it is expected that students' competencies develop throughout the study programme. In general, second-year engineering students report a higher level of self-regulation competencies. However, no significant differences were found. There is a higher percentage of second-year students with an A-score on their self-reflection reports, but no significant differences were found when the distributions of scores were compared across cohorts. At this time, it is not possible to make hard conclusions about the presence of a natural growth, nor about changes in population. Nevertheless, it will be interesting to collect more data and gain more insight into students' self-regulation competencies development. In addition, to really grasp competency development, there is a need for longitudinal research (Van den Broeck et al., 2022).

In the next steps, interventions will be piloted and their effectiveness will be measured, with both quantitative and qualitative measurements. This mixed-method approach is crucial to put the effectiveness of interventions into perspective and thus not only rely on self-reporting methods.

CONCLUSION

If HEIs aim to develop interventions to improve students' lifelong leaning competencies, it is important to define which measurement methods can be used to properly assess students' competencies. This study examined two measurements methods: a self-reported validated questionnaire and the use of a rubric resulting in summative scores. Analysing the self-reported competencies of the students shows that the Dunning-Kruger effect is present. Analysing the summative scores shows that there is possibly natural growth present or that maybe the population has changed. All in all, both methods have their limitations and therefore the use of a mixed-method approach is crucial when determining the effectiveness of interventions.

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BIOGRAPHICAL INFORMATION

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GLOBAL COMPETENCE NEEDS: A COMPARATIVE STUDY OF STAKEHOLDERS' PERSPECTIVES ON ENGINEERING EDUCATION

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ABSTRACT

Upon graduation, engineering graduates will find themselves in diverse, interconnected, and fast-paced work environments. Global competence, which encompasses different types of knowledge, skills and attitudes, is what will help them navigate successfully through the variety of situations they may encounter. Accordingly, its development should be an integrated core aspect of today's engineering education. Acknowledging the problems with current approaches to doing so – in particular, the vagueness of the concept and the issues of prioritizing learning content in already crowded curricula - this paper compares the perceived need and value of specific competencies according to key stakeholders. Based on a previous literature review, a survey focusing on a set of 15 frequently mentioned competences was developed and distributed internationally. The perspectives of three types of stakeholders - engineering professionals (n=339), educators (n=200), and students (n=331) – were collected and broadly analyzed according to the perceived importance of the competencies. Overall, we found agreement among the stakeholder groups, and the majority of our proposed competences were perceived as either important or very important by the respondents. Among the competences, teamwork and collaboration and English language skills stood out, while other language skills were perceived as less important. Comparing the groups, we found that professionals tended to value several social competences more highly and subject-specific competences less highly than academic stakeholders. In our discussion, we offer possible explanations for these findings, which allow inferences for educational change towards a more globally competent higher engineering education.

KEYWORDS

Global Competence, Integrated Learning, Curriculum Development, Stakeholder Perspectives, Engineering Education, Standards 2,3,7,8,10

INTRODUCTION

Industry, accreditation bodies, and educational frameworks such as CDIO or ABET have repeatedly emphasized the need for several non-technical competences for engineering graduates. In addition to issues of employability and professional development (Craps, Pinxten, Knipprath, & Langie, 2020; Pais-Montes, Freire-Seoane, & López-Bermúdez, 2019), the issue of competence has also been repeatedly addressed in the context of education for sustainable development and global citizenship (Brundiers & Wiek, 2017; Quelhas et al., 2019). This scholarly discourse increasingly revolves around competence models that aim to unite knowledge, skills, and attitudes to complement and enable the optimal use of disciplinary technical skills. In addition to the core idea that competences have a behavioral impact, they are also envisioned to be flexibly applicable to different contexts (Bazgan & Norel, 2013; Garcia-Esteban & Jahnke, 2020; Jørgensen, 2012), making them crucial for graduates to navigate rapidly and unpredictably changing work environments. While technical expertise certainly lays the foundation for employment, additional competences that help to view one's work from a holistic perspective and the ability to communicate and collaborate with a variety of different stakeholders can have a significant impact on professional performance and success.

Despite numerous calls to move from long-established, yet outdated, teaching traditions towards new global realities, the wheels of educational progress appear to be turning slowly, and engineering education has been criticized for not sufficiently preparing graduates for the non-technical aspects of their work (Craps et al., 2020). While organizations, accreditation bodies, and scholars have created various lists and models for the specific competences future engineers will need, many of these – having names like generic, transversal, transferrable, global, sustainable, or engineering competences – can only be vaguely defined and are thus difficult to appropriately integrate within curricula. However, the different interpretations of such competences and their perceived importance are likely to affect how educators integrate them within their courses (Richter & Kjellgren, 2022). Additionally, there is the question of whether such “academic” perspectives match those of industry professionals – after all, engineering educators may have begun their academic careers right after their own studies and may have not worked in industry themselves.

Moreover, universities do not merely provide education and training for the profession – they also play an important role in forming the students' conceptions and ideas of their future careers (Garcia & Pinela, 2018). Students may well be affected by their experiences in their engineering classrooms where unintended, implicit messages could be conveyed to them, as the idea of the *hidden curriculum* (Leask, 2005) suggests. Even if educators have an industry background, preparing their students for all eventualities will be a daunting task, not only due to students choosing different career paths and likely changing positions several times, but also due to changing technologies, work environments, and professional demands. This makes it all the more important to identify crucial global competences that will equip graduates with the basic knowledge, skills, and attitudes needed to be able to flexibly adapt to a variety of different contexts and further develop their capabilities in a sense of lifelong learning.

RESEARCH AIM

This paper contributes to a clearer understanding of the perceived need and value of various crucial global competences for engineering graduates around the world. Through comparison of different stakeholders' – engineering professionals, educators, and students – perspectives on the need and value of certain global competences, it addresses both the relative importance of certain competences as well as differences in opinion among these three groups. This compilation of differently perceived competence needs allows inferences for curriculum development in integrated competence learning.

METHODOLOGY

Empirical data was collected through surveys that were internationally distributed from July to December 2022. Contacts from the researchers' university networks were asked to forward the surveys to their institutions' educators, students, and alumni. Altogether, we received 870 responses: 339 professionals, 200 educators, and 331 students. Demographic data shows that respondents included individuals from 54 different universities currently located in 40 different countries, with the majority of them based in Europe. The surveys revolved around a previously identified set of 15 competences that were frequently in the center of relevant literature, and focused on different types of non-technical competences for engineers. Based on this, three slightly different surveys were developed for the individual target groups. Respondents were asked to rank the perceived importance of specific competences within their (or their students') professional field on a 5-point Likert scale, ranging from "not important" to "very important". For the purpose of this study, data was analyzed quantitatively.

RESULTS

Overall, we found a high level of agreement among professionals, educators, and students. Table 1 summarizes the response frequency in terms of mean and mode values and shows that the majority of the competences were perceived as either important (value 4 on the scale) or very important (value 5 on the scale).

Table 1. Frequency comparison of the competences' perceived importance (scale 1-5)

			Professionals		**Educators**		**Students**	
			Mean	*Mode*	Mean	*Mode*	Mean	*Mode*
Knowledge/ Awareness	Communication differences	Intercultural	4.29	*5*	4.25	*5*	3.95	*5*
		Interdisciplinary	4.36	*5*	4.37	*5*	4.14	*5*
	Professional differences	Engineering practice	3.71	*4*	4.04	*4*	4.07	*4*
		Standards/regulations/laws	3.81	*4*	4.01	*5*	4.00	*5*
Skills	Teamwork and collaboration		**4.76**	*5*	**4.66**	*5*	**4.55**	*5*
	Management and leadership		4.31	*5*	4.20	*5*	4.17	*5*
	Adapting to different audiences		4.26	*5*	4.31	*5*	4.08	*4*
	Information searching/analyzing/processing		4.45	*5*	**4.68**	*5*	4.41	*5*
	Language	Local	3.48	*4*	3.72	*5*	3.54	*4*
		English	**4.70**	*5*	**4.75**	*5*	**4.57**	*5*
		Other	2.64	*3*	3.36	*4*	2.83	*3*
Attitudes	Willingness to communicate	Interculturally	4.35	*5*	4.31	*5*	4.16	*5*
		Interdisciplinarily	4.46	*5*	4.43	*5*	4.36	*5*
	Open-mindedness towards others' opinions		**4.54**	*5*	**4.62**	*5*	4.49	*5*
	Sustainability commitment		4.09	*5*	4.41	*5*	4.26	*5*

Among the individual competence rankings, *Teamwork and collaboration*, *English language skills, and open-mindedness towards others' opinions* scored highest, with the most common assessment throughout all groups being "very important." Less importance was placed on *local* or *other language skills*, and *knowledge of differences in professional practices* and *standards/regulations/laws around the world.* Figure 1 on the next page illustrates the individual stakeholder groups' competence assessments in more detail.

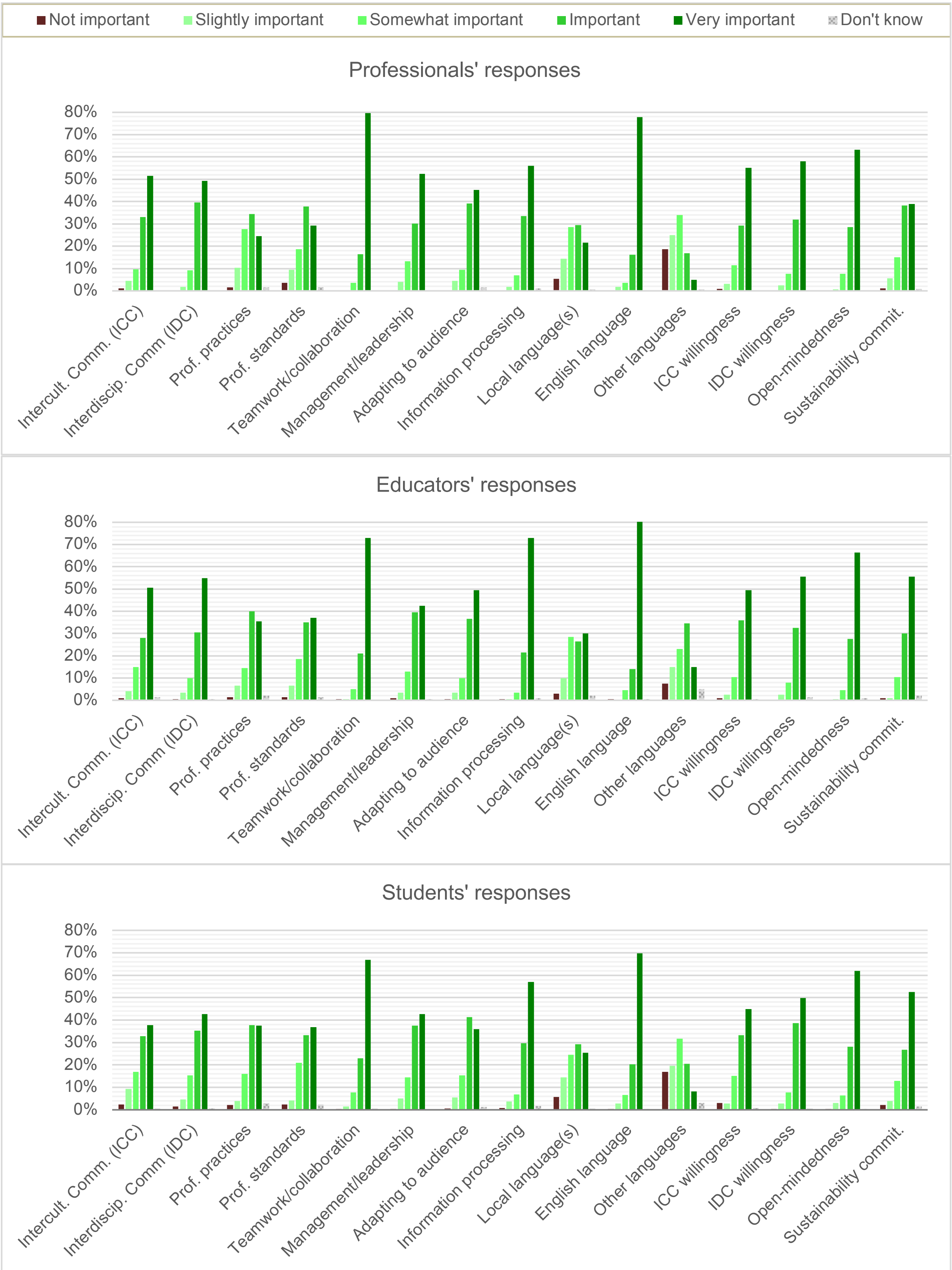

Figure 1. Stakeholder perceptions of the competences' perceived importance

We also compared the individual stakeholder groups' perceptions to see where they agree or disagree with each other. We conducted an independent sample *Kruskal-Wallis test* (CI=0.95, p=0.05), which indicated significant differences between the stakeholder rankings for 12 of the 15 competences. No significant differences were found for the competences of *local language skills*, *willingness to participate in interdisciplinary communication* and *open-mindedness towards others' opinions*. This and the differences between the individual groups' rankings are illustrated in Figure 2 below.

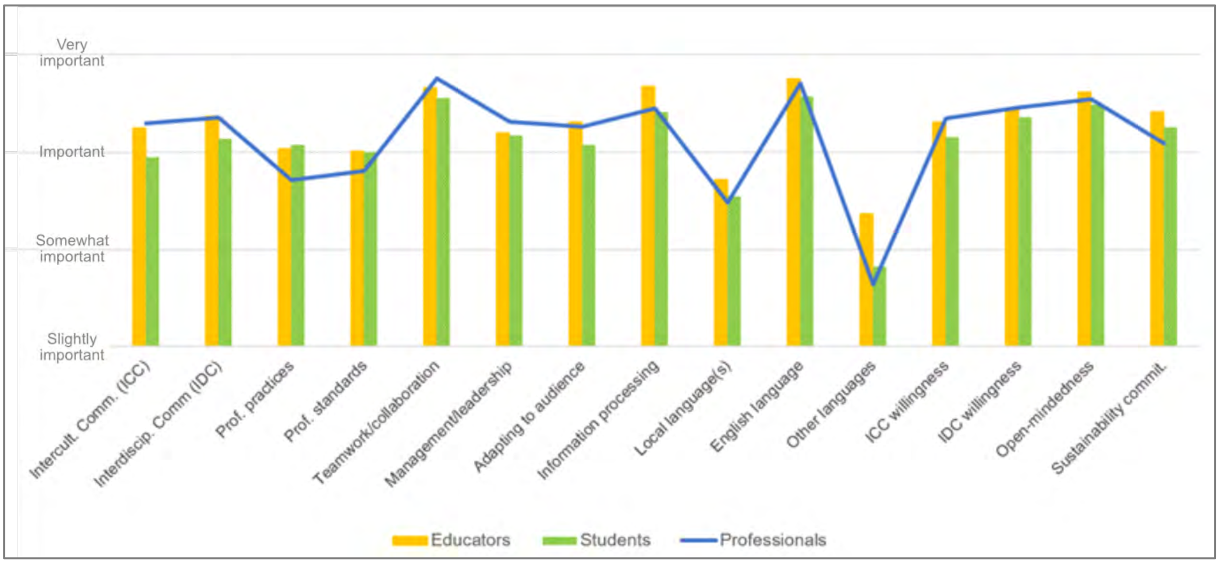

Figure 2. Comparison of the stakeholders' mean competence importance rankings

Considering the professionals' responses as a baseline, due to their first-hand experience as engineers, we decided to illustrate their rankings with a blue line against which the educators' and students' responses were measured. Figure 2 shows the overall agreement among groups and indicates some, albeit minor, differences, most noteworthy among them being:

Professionals tended to rank *knowledge about intercultural and interdisciplinary communication differences*, as well as *willingness to communicate with people from different cultural and professional backgrounds* (ICC and IDC willingness in Figure 2) slightly higher than the other groups, while the ranking for *knowledge about differences in professional practices and standards, laws, and regulations around the world* was slightly lower.

Educators tended to rank all types of *language skills*, particularly *other language skills* (i.e. neither the local language or English), *adapting to different audiences*, *information searching/analyzing/processing*, and *commitment to sustainable solutions* slightly higher than the other groups.

Students tended to generally rank the importance of individual competences lower than the other groups, the only exception being the perceived importance of *knowledge of differences in professional practices around the world*. The competences whose rankings deviated the most from the professionals' baseline included k*nowledge about intercultural and interdisciplinary communication differences* as well as *willingness to communicate with people from different cultural or professional backgrounds.* Similarly, they also ranked other social competences, such as *teamwork and collaboration skills* and *adapting to different audiences* lower than the other stakeholder groups.

DISCUSSION AND CONCLUSION

When we began our research, our intention was to identify ways in which universities could improve their curricula for the development of global competence. In order to provide insights that can be broadly applied to a variety of contexts, some decisions we made, such as removing specific analyses by field and/or location of respondents, also resulted in a loss of specificity. In no way do we deny the importance of a variety of contextual factors that will ultimately play a role in an individual's competence needs, but at the same time we recognize that no education can be tailored to address all the possibilities in a student's career. Today, the world has become so interconnected that graduates will inevitably work with people from different cultures throughout their careers. And as the world becomes more complex, so do engineering fields, programs, and professions. Not only will graduates be surrounded by people from diverse backgrounds, but as they progress through their careers, different sets of competences may be more (or less) advantageous. Thus, it would be difficult or even counterproductive for universities to limit themselves to specific cultural contexts on which to base culture-related learning outcomes. Accordingly, we undertook this study with a vision of a broad approach to competence learning that provides students with the essential foundations and the knowledge, skills, and attitudes needed to continuously develop their global competence. Our analysis follows this vision with a focus on a broadly applicable approach rather than a more discipline- or location-specific one. Based on our findings regarding both the perceived importance of specific competences and the differences in stakeholder opinions and their potential implications, we will now discuss our key findings.

For our analysis, we decided to use the professional engineers' assessment of the competences as a basis for comparison, assuming that their first-hand experiences are exemplary of the current needs of the profession. Global competences are essential assets for professional engineers, and our study showed that not only industry professionals, but also engineering educators and students seem to be aware of their value. Given the recurring criticism that engineering education does not fully meet the needs of industry (Craps et al., 2020; Pais-Montes et al., 2019), we were surprised to find such similar response patterns among our different stakeholder groups. Our findings suggest that both engineering educators and students may have a good idea of the future non-technical competence needs of graduates. While this finding is promising for engineering education, mere awareness of skill needs must be followed by action. After all, graduates merely believing that English language skills are important will not be very meaningful if they do not actually acquire these skills. Similarly, believing that teamwork and collaboration skills are important does not mean that one will behave in appropriate ways in environments that require them. To assist universities in fostering the development of global competence, we will examine some important patterns in our data and offer considerations for how our findings might affect engineering education for the development of global competence.

Looking at patterns in the rankings, it is clear that what could be considered social competences – knowledge about intercultural and interdisciplinary communication differences as well as a willingness to communicate with people from such different backgrounds, teamwork and collaboration skills, management and leadership, adapting to different audiences, and open-mindedness – were consistently ranked high by the professionals, signifying a great importance of them in professional contexts. While the majority of them had similarly high rankings, the competence *teamwork and collaboration* stood out, suggesting that graduates will have to work a lot in collaborative environments. *Management and leadership* was ranked slightly lower, presumably due to the survey questions focusing on recent graduates, who may typically only assume leadership positions in later stages of their careers. Nevertheless, these social competences were also the ones in which the students' rankings were also consistently lower than the professionals', while the educators tended to be closer to the professionals' baseline. This missing awareness of the value of social competences raises some important questions for education.

If educators are aware of the need for such competences, how can they ensure student awareness and acquisition of social competences? We have already raised the point that mere awareness does not necessarily mean that (curricular) action will be/is being taken. From our own experience we know that many educators may directly, or likely more often, indirectly address such issues through team assignments or group projects. Authors researching similar issues have emphasized the strong educational value of activities mirroring professional situations, such as group assignments (Kahn & Agnew, 2017), project work with stakeholders (Corple, Zoltowski, Kenny Feister, & Buzzanell, 2020) or international (virtual) collaborations (Kang, Kim, Jang, & Koh, 2018; Schech, Kelton, Carati, & Kingsmill, 2017), or work placements (Downey et al., 2006). Such activities also fit well within the active or experiential learning approach promoted by the CDIO initiative (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014). However, to ensure that such activities can live up to their potential, it is essential that the thoughts and reasoning behind them are made clear to the students (Richter & Kjellgren, 2022). If educators want their students to be aware of their relevance, they should not merely assume that students recognize related assignments or activities as mirroring, or preparing them for, future work environments, but should instead take some time to highlight these considerations.

A second competence cluster showing interesting patterns revolved around languages. English language skills were perceived as highly important throughout our sample and were ranked highest among both academic stakeholder groups and as a close second (behind teamwork) by the professionals. Considering the predominance of English terminology in many technical areas and its current status as de-facto lingua franca of international work environments, its perceived high importance is of no surprise. Looking at the respondents' background, only 10 professionals (2.9%), 2 students (0.6%), and 1 educator (0.5%) were at the time of the survey residing in an English-speaking country. Engineering professions are becoming increasingly global in nature (Downey & Lucena, 2005; Jesiek, Zhu, Woo, Thompon, & Mazzurco, 2014), and English language proficiency plays a major role for communication in diverse international contexts. Nevertheless, the comparatively low importance attributed to the local language was striking, as we may assume that many organizations will have close ties or at least some professional contact with actors within local environments, where local language skills should play a role. Maybe such interactions are seldom or are perceived as simple enough so that our respondents considered local languages as only somewhat important? Maybe teams are already so internationalized or are becoming so internationalized in the competition for international talent that organizations choose English as their corporate language? This could, potentially, also be a sign of short-sightedness on the part of the respondents, not seeing beyond strict work requirements or realizing other important functions of local language proficiency, which may range from bridging the gap between "English-talking elites" of engineering professionals and the local stakeholders to the enabling of a deeper and more meaningful integration in society for internationally recruited staff. It could, however, also be a sign of language teaching simply not being properly aligned with the agenda of the technical university, which would be a shortcoming well worth addressing.

The final thematic cluster comprised competences more closely related to specific professional fields and revolved around the knowledge of differences in professional practices, professional standards/regulations/laws of the specific engineering field around the world, and finally competences related to a commitment to sustainable solutions. On average, all three of them were perceived as important, although sustainability commitment received a slightly higher ranking from all stakeholder groups. Interestingly though, this cluster is the first instance where educators and students tended to attribute a slightly higher importance than the professionals. The current educational imperative for sustainable development may certainly help account for the high value the academic stakeholders place on it, but it could be that sustainable development, in its many facets, is either not reflected on, or prioritized in our respondents' work assignments. That knowledge of differences in professional practices or standards/regulations/laws was considered not as crucial by the professionals could be explained by a mere awareness of the existence of such differences being considered sufficient. Maybe this awareness as a basis for learning more about aspects relevant to one's individual work situation was considered to be enough.

Educating graduates who are not only technical experts but also globally competent is an ambitious goal for engineering universities. Curricula with room for high quality learning of all such competences is a daunting challenge, and universities will have to ensure their students can absorb the contents without becoming overwhelmed by efforts to fit it all in. In regard to global competence, several questions are raised: First, what are the basic competences that really could or should be addressed during engineering education and what can be done later? As we stated earlier, competences do range among fields and jobs and are highly dependent on individual situations. Second, where should competences fit within the students' education? Should they be part of individual program curricula or be offered as extra-curricular activities? Should universities address learning specific language, culture, or communication courses in-depth, or should smaller aspects be integrated into disciplinary courses so that students see the competences in action? Of course, the ideal(istic?) solution would be to weave competence learning throughout the student's education, but that may, at least at the current time, be more utopian thinking than a realistic option.

Finally, it should be noted that the complex, interrelated nature of global competence and its need to allow for flexible adaptation to a variety of contexts may make it seem elusive to those with little experience of the subject. The behavioral expression of global competence can be seen as any behavior that is both effective and appropriate to a given situation, which may vary widely between different contexts. A globally competent person recognizes this and is able to draw flexibly, perhaps even unconsciously, on a range of knowledge, skills, and attitudes that lead to these behaviors. From an educational perspective, the transfer of knowledge and skills seems much more straightforward and easier to assess than the less obvious attitudes that a learner may hold. However, some of the attitudes that we and stakeholders have identified as important for global competence, such as openness or willingness to communicate with people from different cultural or professional backgrounds, can be easily addressed by raising learners' awareness of the potential benefits that such interactions can bring. The fact that certain knowledge can lead to the formation of attitudes shows how global competences are intrinsically linked. More importantly, it also shows that multiple variations of different competences can ultimately lead to the effective and appropriate behaviors needed in specific contexts. Nevertheless, the goal of addressing multiple global competences in education may allow for a broader and ultimately more refined set of competences. After all, while there is a range of what people with whom one interacts may consider effective and appropriate, certain behaviors are likely to lead to more advantageous outcomes than others, and the better prepared individuals are, the more likely they are to be able to identify which types of behaviors these might be.

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INTEGRATING SUSTAINABLE DEVELOPMENT IN A COMPUTER SCIENCE PROGRAM: A REVIEW

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ABSTRACT

The Computer Science program of the School of Engineering at the Universidad Católica de la Santísima Concepción is working to adopt CDIO Optional Standard 1: Sustainable Development and cover sustainable development in an integrated manner in the current study plan. Hence, we wish to know which strategies have been applied to promote sustainable development in Computer Science, both at the curricular and pedagogical levels. To answer this question, we performed a review of relevant peer-reviewed articles and conference papers retrieved from online databases. Even though our focus is Computer Science, we expanded our search to consider Information Technology, Information Systems, Informatics, and other STEM programs, as many strategies for these fields are similar and thus their results are also applicable. Our preliminary results show that, in general, sustainable development in Computer Science has been approached at the curricular level and at the pedagogical level. In the first case, programs define the competences, knowledge, skills, and attitudes required to address sustainable development challenges. However, there is no clear consensus on which specific competences, skills or knowledge should be included in the curriculum, nor when and where they should be addressed. At the pedagogical level, the literature on sustainable development education shows that, while some higher education institutions still favour traditional lecture-based courses, active learning methodologies are the prevailing trends. Among the works reviewed, we find many examples of problem-based learning, project-based learning, game-based learning, challenge-based learning, case studies, and debates being used. The main contribution of this work is to serve as a guide in integrating sustainable development in a Computer Science program by defining program goals and learning outcomes related to environmental, social, and economic sustainability for our Computer Science curriculum reform process. Furthermore, this work can contribute to the selection of appropriate pedagogical approaches to sustainability teaching and learning.

KEYWORDS

Computer science, Sustainability, Standards: 2, 3, 7, 8, 9, 10 Optional standards: 1

INTRODUCTION

The Computer Science program of the School of Engineering at the Universidad Católica de la Santísima Concepción is facing a curricular reform process. Among its goals is the adoption of CDIO Optional Standard 1: Sustainable Development, which in a recent self-assessment process was evaluated at an achievement level of 1 in the CDIO rubric for that standard (Martínez-Araneda et al., 2022). Currently, the Computer Science program includes a mandatory course on Environment and Energy, and students usually work on projects focused on the UNDP Sustainable Development Goals in their first-year introductory course projects and in some latter-year projects, but sustainable development is not covered in a systematic and integrated manner in the current study plan. Our medium-term goal is to reach an achievement level of 3 in the CDIO rubric for the Sustainable Development standard: *There are explicit program goals and intended learning outcomes related to environmental, social, and economic sustainability and at least three substantial sustainable development learning experiences of increasing complexity including an introduction early in the program* (Malmqvist et al., 2020).

The UN defines Sustainable Development *(SD)* as *development that meets the needs of the present without compromising the ability of future generations to meet their own needs* (Brundtland, 1987). On the other hand, UNESCO states that Education for Sustainable Development (ESD) *gives learners of all ages the knowledge, skills, values, and agency to address interconnected global challenges including climate change, loss of biodiversity, unsustainable use of resources, and inequality. It empowers learners of all ages to make informed decisions and take individual and collective action to change society and care for the planet. ESD is a lifelong learning process and an integral part of quality education. It enhances the cognitive, socio-emotional, and behavioural dimensions of learning and encompasses learning content and outcomes, pedagogy, and the learning environment itself* (UNESCO, 2022). Moreover, the UN 2030 Agenda for Sustainable Development defines its target 4.7, Education for sustainable development and global citizenship as: *By 2030, ensure that all learners acquire the knowledge and skills needed to promote sustainable development, including, among others, through education for sustainable development and sustainable lifestyles, human rights, gender equality, promotion of a culture of peace and non-violence, global citizenship and appreciation of cultural diversity and of culture's contribution to sustainable development* (United Nations, 2015).

Sustainable development has been a peripheral subject in most computing-related engineering programmes. In particular, computing-related programmes in Chile are rather inflexible giving students little leeway to take optional credits in other areas of interest. In our experience, the latest generation of computer science students are more aware and concerned about sustainability issues such as global warming and climate change but find it hard to relate these concerns to current computing competences. For example, there is little discussion of the effects of IT on the environment and its carbon footprint is not covered in the curriculum. The challenge for our curricular reform process is, then, how to incorporate these topics into the curriculum, balancing sustainable development at a general level versus as it specifically relates to computing. At the same time, it must handle the tension between teaching SD facts versus an emphasis on students' reflections and/or practicing skills (Eriksson, 2016).

In this work, we present the results of a literature review aimed at identifying what kinds of strategies have been applied to promote sustainable development in computing-related engineering programs, both at the curricular and pedagogical levels.

REVIEW METHODOLOGY

We performed a narrative review (Bearman *et al*., 2012) of relevant literature retrieved from online databases. Our inclusion criteria are articles focusing on higher education, published in journals and conference proceedings either in English or Spanish. Our exclusion criteria discarded articles published before 2007, the year of the School of Engineering's major curricular reform for all its programs where the CDIO approach was adopted. The search was limited to peer-reviewed articles and conference papers in full text, extracted from databases such as the Wiley Online Library, Elsevier ScienceDirect, the CDIO Digital Library, and the ACM Digital Library, among others. Even though our focus is Computer Science, we expanded our search to consider Information Technology, Information Systems, Informatics, and other STEM programs, as many strategies for these fields are similar and thus their results are also applicable.

Our research questions focus on integrating sustainable development into computer-related engineering programs regarding the curriculum and those pedagogical strategies used to acquire different competency levels. Thus, our research questions are:

Research Question 1: What concrete actions have been taken to include sustainability in computing-related engineering program curricula?
Research Question 2: Which active learning experiences have been applied to aid the development of the SD competence in students?
Research Question 3: Are these ESD learning experiences at an introductory, intermediate or advanced complexity level?

RESULTS

The above-mentioned databases were consulted using the search terms "Sustainability" and "Sustainable Development", and "Computer Science", "ICT", "Computer Technology", "STEM", "Engineering Education", among other similar terms. These results were then reviewed and filtered to yield 57 articles, which were then analysed to answer our research questions. In this literature review, we aim for a qualitative rather than a quantitative analysis. In the following sections we present our principal results for our research questions.

Results for Research Question 1

To analyse our findings for the first research question, we find it useful to refer to the degrees of sustainability integration into the curriculum presented by Huntzinger et al. (2007): at the first level, "Bolted On", sustainable development is acknowledged in the goals or mission statement of the program, but there is limited integration in courses or in the curriculum. For example, sustainable development might be present in one course or as a module in several courses at the junior or senior level. At the next level, "Built-in", SD is integrated into the goals and mission statement of the program and significant effort has been made to integrate concepts and methods into the existing curriculum at all levels. At the highest level, "Redesign", sustainable development has become an essential element of the program goals and significant effort has been made to rethink and redesign and program to completely integrate concept into the curriculum at all levels.

Most of the articles included in our sample, with a few exceptions, present approaches that fall into the "Bolted-On" category: sustainable development is included into computer science programs as modules in specific courses or as a special course dedicated to the topic in an study plan otherwise lacking any other coverage of sustainable development, or at least, the information provided by the authors does not allow us to infer otherwise. For example, Cai (2010) has created specific green computing modules that can be added to other CS courses; Cayzer (2010) discusses designing sustainability units for courses in the Innovation and Technology Management MSc at Bath University; Abernethy and Treu (2014) describe how they added a self-contained one-week module on sustainability to the Introduction to Information Technology course about IT's role in sustainable development; Hilty and Huber (2017) discuss lectures given as part of an Informatics and Sustainable Development course and as guest lectures in the courses "Sustainable Development for Computer Science and Engineering" and "Sustainable Development, ICT and Innovation". Stone (2019) has created sustainable development projects to be incorporated as modules in five other courses. Likewise, Cai (2010) developed a Green Computing and Network Services course, Eriksson et al. (2016) describes three introductory courses on sustainable development in three different ICT-related programmes at KTH. Fisher, Bian and Chen (2016) also provide several examples of computing courses related to sustainability.

In our sample, an example of the "Built-in" approach is the work of Gimenez-Carbo *et al.* (2021), which presents a study on the development of the cross-curricular learning outcome (CCLO) "Ethical, environmental and professional responsibility" for students of different bachelor's degrees taught at the Universitat Politècnica de València, Spain. In particular, this learning outcome is covered in three compulsory courses and two optional courses of the bachelor's degree in Telecommunication Technologies and Services Engineering, via case studies, gamification and simulation.

In our review, many authors discuss the need for a comprehensive curricular redesign to incorporate SD into a study program under institutional guidance and support. Nuñez et al. (2020) present an "Redesign" exemplar: a case study on integrating sustainable development into a bachelor's degree curriculum at the Tecnológico de Monterrey, Mexico. This curriculum reform was designed to incorporate design project courses ranging from the 3rd. to 9th. Semester of studies and includes sustainable development content at every level.

Results for Research Question 2

Our literature review shows a great diversity in the active learning pedagogical strategies used in education for sustainable development, with project-based learning and reflective activities being the most prevalent. In the following sections, we present an incomplete list of examples for common pedagogical strategies used in ESD.

Project-based learning

Works by Weber et al. (2014), Eriksson *et al.* (2016), Marasco *et al.* (2016), Stone (2019), Gimenez-Carbo *et al.* (2021) all describe applying project-based learning in introductory courses incorporating sustainability themes.

Games-based learning

Game-based learning is a pedagogical strategy that is very appealing in computer-related programmes, as it encourages student engagement and reflection. Eriksson *et al.* (2020) uses systems thinking games in an introductory course on sustainability and media technology. Swacha *et al.* (2021) make the case for the effectiveness of using game-based learning for sustainable development education, and describe Eco JSity, an interactive educational game for solving classic algorithmic problems with JavaScript code, whose storyline, game space, and rules are all themed around sustainable development. Gimenez-Carbo *et al.* (2021) also describe the development of the cross-curricular learning outcome “Ethical, environmental and professional responsibility” for students of different bachelor’s degree programmes using gamification and simulation.

Debates

Cayzer (2010) talks about encouraging student debate as a way to discuss the role of sustainable IT in modern society. Casañ *et al.* (2020) present a 29-year history of the Social Impact and Professional Ethics of Informatics course at the Barcelona School of Informatics at UPC, which has students debate case studies about sustainable development in class and/or online. Alaswad and Junaid (2022) describe how they incorporate educational debates on sustainability and climate change in a course in the Mechanical Engineering programme at Aston University.

Challenge-based learning

Eldebo et al. (2022) and Norrman et al. (2022) cover the use of challenge-based learning in four courses in the Erasmus+ project *ScaleUp4Sustainability*, driven either by a provided external challenge or by aiming at one of the Sustainable Development Goals (SDG) or similar known societal challenges.

Case studies

Abernethy and Treu (2013) explain how they added a case study on sustainable development to an upper-level Project Management class, where several lectures and discussions were devoted to the issue of sustainability and its relationship to information technology (IT). Casañ *et al.* (2020) also discuss presenting case studies about sustainable development in class and/or online for student discussion. Gimenez-Carbo *et al.* (2021) also describe using case studies to motivate the development of the “Ethical, environmental and professional responsibility” cross-curricular learning outcome.

Seminars and lectures

Seminars and lectures are a very common pedagogical strategy which is also useful for education for sustainable development. Penzenstadler and Fleischmann (2010) incorporate sustainability into student discussions by starting with a master’s seminar, later progressing to a student-led lecture series and finally establishing the topic in Teach-The-Teacher seminars and by integrating it into software engineering courses. Eriksson et al (2016) mention using lectures and seminars in three introductory sustainability classes.

Capstone projects

Cai (2010) has supervised several senior thesis projects on green computing. Palacin-Silva *et al.* (2017) describes four capstone projects developed by students from the Erasmus Mundus Master Course in Pervasive Computing and Communications for Sustainable Development (PERCCOM), showing how a sustainable development focus can be integrated into a traditional software engineering course.

Results for Research Question 3

Regarding the complexity level of the ESD learning experiences studied in this literature review, most of them are meant to be introductory experiences that incorporate sustainable development themes into computer-related engineering programmes. Also, the works reviewed do not state whether these are starting points for more advanced experiences in the curricula. A few of the articles found by this literature review belong to an intermediate or advanced level of studies. Cayzer (2010) talks about designing sustainability units for the Innovation and Technology Management Master of Science programme at Bath University, Penzenstadtler and Fleischmann (2010) discuss creating a master's seminar on sustainability, and Palacin-Silva *et al.* (2017) reports on capstone projects of a Master program focusing on sustainable development.

DISCUSSION

From our literature review, there is a widespread agreement on the importance of integrating sustainable development into all STEM programs (CDIO Standard 3). However, our work has shown a lack of consensus on guidelines for computer-related engineering curricula regarding either which core competencies (CDIO Standard 2) must be developed or how to update the curricula for effective competence development (Gamage *et al.*, 2022). For example, there is much discussion in the literature on which specific sustainable development topics make up the core curriculum, similarly to what is found by Faludi and Gilbert (2019), Pennington *et al.* (2020) and Martinez *et al.* (2021). Weiss *et al.* (2021) identify six distinct patterns for implementing education for sustainable development in higher education institutions, according to two distinct implementation phases: education for sustainable development can be implemented from the bottom-up, from the top-down, or both, and the impetus for change can come from within or from external stakeholders.

Gamage *et al.* (2022) state that the most appropriate pedagogical approaches for education for sustainable development problem/project-based learning, real-world or experiential learning, case studies and e-learning, as these are the most likely to effect change in individual behaviour toward sustainability goals by enhancing the domains of knowledge, skills and attitudes expected in ESD (CDIO Standard 7, 8). Our literature review reveals that most works discussed in the Research Question 2 review implement these pedagogical strategies. However, ESD requires systems thinking that considers foresight, long-term effects and the understanding of system interconnectedness, essential topics to address sustainability issues. As mentioned in Research Question 9993, most ESD experiences reviewed in this work are aimed at an introductory level and more advanced experiences are required in the curriculum to properly acquire mastery of SD competencies (Torre *et al.*, 2017; Gomes *et al.*, 2019; Chatterjee and Rao, 2020; Hansson *et al.*, 2022).

Our literature review also uncovered several barriers to the effective integration of sustainable development into computer-related engineering programmes. Among them, at the institutional and administrative levels, ESD requires support through resources, coordination, and appropriate incentives (Torre *et al.*, 2017). Long-term commitment to ESD must encompass not only a few study programmes that relate to the environment, but rather requires a campus-wide effort to change institutional cultures to ensure changes not only in program competencies but also in attitudes and behaviours toward sustainability at all levels.

Embracing sustainability may also challenge current teaching practices and require efforts to enhance faculty teaching competences (CDIO Standards 9 and 10). Finding motivated teachers that are competent in their own fields and knowledgeable about sustainability is a difficult task. Faculty members must be prepared to work interdisciplinarily and transdisciplinarily with other faculty to tackle sustainable development themes, no easy task for computing-related programs, where IT's carbon footprint is mostly ignored, and reduction approaches are rarely worked upon with other engineering disciplines. Likewise, students should be prepared to work with other students from other programs and disciplines to address sustainability problems across disciplines in an efficient and orderly manner (Koniukhov and Osadcha, 2020). To that extent, faculty members must lead the way by setting an example. In our institution, since 2020, progress was made in aspects of disciplinary improvement (standard 9) and enhancement of faculty teaching competences by the issuance of 2 diplomas in innovation for university teaching (standard 10), but its effects in the teaching practices are still to be seen (Martínez-Araneda et al., 2022).

CONCLUSIONS

In this work, we present a literature review aimed at answering research questions regarding integrating sustainability into computer-related engineering programmes. Our results show that most curricular activities are still at the "Bolt-On" level: not fully integrated into courses nor into the curriculum. The literature discusses many examples of sustainable development being integrated into introductory courses of sustainability-oriented multidisciplinary courses, of latter-year capstone courses where students work on sustainable development projects and on senior theses on computational sustainability. Our findings from the collected data suggest that sustainability is under-represented in the computer science curricula. Furthermore, students would benefit from exposure to SD all through their study program and that there are many pedagogical strategies for this purpose which may be adopted depending on the course. Nevertheless, sustainable development is being promoted in the formal and informal curriculum.

At the pedagogical level, the literature on sustainable development education shows that, while some higher education institutions still favour traditional lecture-based courses, active learning methodologies are the prevailing trends. Among the works reviewed, we find many examples of problem/project-based learning, game-based learning, challenge-based learning, debates, case studies, capstone projects, and seminars and lectures being used. Our review also shows a lack of an SD experience track to achieve advanced competence levels and that there is no silver bullet to integrate SD into the curriculum.

The main contribution of this work is to serve as a guide in integrating sustainable development in a Computer Science program by defining program goals and learning outcomes related to environmental, social, and economic sustainability for our Computer Science curriculum reform process. Furthermore, this work can contribute to the selection of appropriate pedagogical approaches to sustainability teaching and learning.

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BIOGRAPHICAL INFORMATION

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CONSTRUCTIVIST PRINCIPLES AS USED FOR ENHANCING ACTIVE LEARNING – CASE: ENGINEERING THERMODYNAMICS

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ABSTRACT

Engineering Thermodynamics is an important engineering discipline in universities, concerned mainly with traditional and alternative sources of energy in terms of availability, movement, and conversion. However, much discontent can be found in the literature regarding teaching deficiencies and recognized learning difficulties associated with this subject. Many attempts have been tried, such as the blended learning approach, active learning techniques, computer-based instruction, critical thinking enhancement and the use of technology such as a virtual laboratory. In the present contribution, the principles of the constructivist approach are integrated in order to enhance students' active learning. This is very relevant when using the CDIO approach which emphasizes active learning (CDIO Standard 8). The new constructivist learning elements include a much greater emphasis on coaching, scaffolding, and modelling. The improvement of student learning and retention of concepts after integrating the principles of the constructivist approach is measured using a pre- post-assessment experiment. The findings encourage engineering educators and educational institutions to prefer constructivist principles over traditional principles to (1) increase more effectively students' interest in Engineering Thermodynamics, (2) ensure more effective learning of the general understanding of Engineering Thermodynamics, and (3) support more effectively students' learning of knowledge and skills required to solve more difficult Engineering Thermodynamic problems.

KEYWORDS

Constructivist principles, Learning effectiveness, Active learning, Thermodynamics, CDIO Standard: 8.

INTRODUCTION

Thermodynamics is taken by students in the majority of university engineering programs, mechanical, chemical, civil and electrical, as well as by students studying physics and chemistry, although with some variations in the topics covered, depending on the discipline involved. Often in an engineering program, thermodynamics comes early, possibly in the second or even first year of a four-year course, as it teaches fundamental concepts and acts as a pre-requisite for other later courses. Manteufel (1999) has described thermodynamics as the 'gateway' course in mechanical engineering in the sense that students' performance in the subject is in good correlation with how the students do in the rest of the courses in the curriculum. However, the fundamental concepts within engineering thermodynamics are quite often considered difficult to grasp by students. Students' expressions of dissatisfaction and frustration are very common (Cobourn & Lindauer, 1994; Meltzer, 2006; Grigull, 1990) as is evidence of widespread poor learning of basic concepts and principles of thermodynamics by university students (Lape, 2011; Abulencia *et al.*, 2012; Meltzer, 2004; Loverude *et al.*, 2002; Prince *et al.*, 2009; Jasien & Oberem, 2002). There is even a culture of simply accepting the status quo by students who make remarks like 'one cannot understand thermodynamics, only get accustomed to it' (Grigull, 1990).

This last remark may well give a clue as to what should be included in an introductory course to engineering thermodynamics. It indicates a desire on the student's part for proofs of the axioms of thermodynamics, i.e. the principles, which in fact do not exist. The issue of how the validity of the principles can be established is an old and familiar problem for the theory of cognition. Deduction could be used, but this may not always correspond with reality. Another way is to use refutability, which, to a student may prove frustrating as there is no final prove except by constant refutation. Basically, the principles of thermodynamics form a reliable basis of our knowledge simply because all our efforts have failed to refute the principles. This is a difficult logical structure for students new to thermodynamics to grasp. This is particularly true since the degree to which the principles of thermodynamics influence daily life, as well as many areas of applied sciences, cause students to perceive them as 'long-proven' laws of nature (Grigull, 1990). The students must simply 'get accustomed' to the fact that the principles are empirical and by their nature cannot be proven; and that they are only a reliable basis for our understanding and use as long as it has not been possible to refute them, but that such a possibility remains open. Such a concept is far removed from the 'naïve' approach of many students (Grigull, 1990). From this, it could be deduced that in a first course in thermodynamics the students should be made aware of the general fundamentals, the most important applications such as the principles, the equation of state and the various cycles. Only in a later course can the logical structure of thermodynamics including the concepts of thermodynamic potential and thermodynamic consistency be introduced.

This is especially true within a CDIO learning environment where the emphasis is on active learning (CDIO Standard 8). Here students need to master the basic concepts of thermodynamics in order to be able to design solutions to applications where a deep knowledge of thermodynamic theory, and especially the first and second laws, is needed.

The purpose of this research is to explore how the principles of constructivism can help where pedagogical constructivism is used and 'is concerned with the teaching and learning process with particular attention to the knowledge constructed within the learner, differentiated for each learner (Wink, 2014).

In the paper, a brief discussion concerning the advantages and disadvantages of using a pedagogical constructivist approach in general is followed by a detailed description of what was involved in applying such an approach to the teaching and learning of engineering thermodynamics. There then follows an extensive experiment investigating if such an approach is of benefit to the student learning, especially the student learning and retention of what can be quite abstract laws and principles found in engineering thermodynamics.

THE PEDAGOGICAL CONSTRUCTIVIST APPROACH

The emergence of constructivism as the prominent learning theory in colleges and universities has resulted because of the movement from behaviorism to cognitivism and now the constructivist perspective (Cooper, 1993). Behaviorism stresses performance acquired by short-term learning techniques designed to pass tests and accomplish tasks. The problem that arises is that after a period of time students can no longer remember or apply what has been learned. Instruction is teacher-centered and accomplished in a didactic manner with much teacher-talk, disseminating information to the passive recipients. Other aspects of traditional classrooms primarily include (1) over-reliance on textbooks which generally only offer one worldview, (2) discouragement of cooperation which leads to higher order reasoning that working in isolation limits, and (3) seeking correct answers instead of allowing students to work through intricate issues which would result in knowledge construction and deep learning. Constructivism emphasizes knowledge construction in contrast to knowledge transmission along with the mainly passive recording of information transferred by a teacher, instructor or lecturer. Construction of knowledge can be facilitated in educational student-centered environments that encourage students to appreciate uncertainty, inquire responsibly and search for understanding (Brooks & Brooks, 1999). Through the processes of self-reflection and questioning, analyzing, evaluating and problem-solving learners become active and independent constructors of knowledge (Wink, 2014; Cooper, 1993). Thus, from a constructivist theoretical viewpoint 'learning' produces long-term understanding while 'performance' culminates in limited recollection of concepts as time goes on.

Brooks and Brooks (1999) declare that learning and education should be a time of curiosity, exploration and inquiry and that memorization must take a secondary role. Learning how to solve real-world problems by constructing new knowledge through the critical process of creativity and implementation of original ideas supersedes memorization and repetitious reproduction of existing knowledge and concepts. Constructivism acknowledges the importance of prior knowledge and experience and learning is an ever-evolving growing process, and not only an accumulation of knowledge (Proulx, 2006). Instead, cognitive development must ensue and result in individual constructions of understanding. In traditional learning environments if learners can learn procedures and reproduce chunks of information then the perception is that learning has taken place. From a constructivist perspective 'imitative behavior' is not what is required; deep learning is the goal and is demonstrated by what students can 'generate, demonstrate or exhibit' (Brooks & Brooks, 1999). It becomes apparent that traditional teaching to a large extent is inadequate and needs to be replaced by the constructivist paradigm which encourages active construction of meaning that produces concept development, deep understanding, structured knowledge acquisition, and which fosters higher levels of autonomy (Beerenwinkel & von Arx, 2016).

The general consensus among educators worldwide is that thermodynamics is challenging and difficult to understand; this results in two major areas of concern: Poor achievement and retention of knowledge (Mulop *et al.*, 2012). Therefore, research engaged in enhancing teaching and learning for this subject is relevant and needful. In a study conducted with undergraduate thermodynamics students, it was concluded that the most important factor when teaching this subject is to determine what the student already knows, what prior knowledge they have and to then teach accordingly (Holman & Pilling, 2004). The blended learning approach (Bullen & Russell, 2007), active learning environment (Hassan & Mat, 2005), computer-based active learning materials (Anderson *et al.*, 2002), as well as modelling, scaffolding and coaching (Jonassen *et al.*, 1993; Jonassen, 2009) proved to be effective methods of enhancing teaching and learning in thermodynamics (Mulop *et al.*, 2012) and increasing interest without forfeiting rigor or quality (Brooks & Brooks, 1999).

Active learning, knowledge construction, collaborative learning, coaching, scaffolding and modelling are all consequential constructivist teaching pedagogy components for enhancing the learning of thermodynamics for engineering students. Active learning is characterized by student-centered collaborative learning environments wherein learning is not passively transmitted. Students ask themselves questions, analyze, reflect and work on problems and actively construct knowledge individually and in groups. Learning is an active process wherein students autonomously take responsibility for their education to a large extent (Hessenauer *et al.*, 2019). The scaffolding component requires active involvement; support given depends on what the learner already knows and what the learner is capable of accomplishing with the support of the more knowledgeable interlocuter (instructor or peer). Over time support is slowly withdrawn or minimized until the student is able to take responsibility for learning. As previously stated above, a good starting point is to assess the current knowledge of the students. Questions such as: Do you know what to do; have you done a problem like this before; will your past experience help you solve this problem (Holton & Clarke, 2006)? Once the instructor has determined the level of support which is needed there are several options which include (1) feeding back, (2) hints, (3) instructing, (4) explaining, (5) modelling and (5) questioning (Van de Pol *et al.*, 2010). For example, the instructor provides small pieces of information or makes suggestions (hints) to students who are working on solving problems – just sufficient to keep the process moving forward but not too much to interfere with autonomy (Hessenauer *et al.*, 2019). 'Hints' could also be described as "coaching" with regard to scaffolding. Modeling is another scaffolding strategy, where expected behavior, skills or knowledge is demonstrated in a Vygotskian inspired way (Van de Pol *et al.*, 2010). Participants are both active participants and build "common understanding or intersubjectivity through communicative exchanges in which the student learns from the perspective of the more knowledgeable other" (Van de Pol *et al.*, 2010). This is known as the Zone of Proximal Development (ZDP) which enables a student's developmental growth with scaffolded support to ensure that the learner can accomplish learning goals which could not be achieved alone. For the focus of this study, scaffolding will refer to face-face communications with a specific emphasis on student-teacher interactions. This in contrast to types of support offered that do not involve active interactions. The purpose of the clarification is to appease opponents (Pea, 2004; Puntambekar & Hübscher, 2005) who claim that the theoretical context has been lost and that scaffolding has become a synonym for support (Van de Pol *et al.*, 2010).

The components of the behavioral framework as presented in Table 1 are powerful descriptors which if applied can improve instruction and result in improved performance and retention of knowledge. Accepting and encouraging autonomy is a critical component of constructivist teaching. Once questions have been posed or problems assigned, the instructor must provide sufficient 'wait time' in addition to the acknowledgement of student autonomy, to ensure the development of critical thinking ability and discovery (Hessenauer *et al.*, 2019). The opportunity for students to discern in a transformation-seeking classroom where students seek connections between ideas and concepts will provide learner autonomy and initiative (Brooks & Brooks, 1999). The development of autonomy necessitates the need to provide enough time for the completion of challenging problems and questions. A better approach to asking questions or posing problems is to allow group discussion and then to later give the groups the opportunity to give whole group feedback. Furthermore, in order to stimulate mental activity, it is important to frame tasks generated from Bloom's Taxonomy so as to generate new understandings and constructions of knowledge. Lexis such as design, develop, investigate (create); appraise argue, judge critique (evaluate); relate, contrast, examine, experiment (analyze); and solve, demonstrate, interpret (apply) will facilitate constructions of new understanding. In addition, dialectical or social constructivism which emphasizes discussion, sharing and debate among learners is critical to the construction of new understanding (Rogoff, 1990). Students collaborate in small groups helping others find meaning while refining their own (Applefield *et al.*, 2001). Teacher-student and student-student social negotiation are essential for the emergence of multiple perspectives, reflection, the advocacy of ownership of learning, and self-awareness (Hessenauer *et al.*, 2019). Moreover, instructors use social interaction to scaffold tasks enabling students' understanding of difficult concepts using various strategies as discussed above.

Table 1. Constructivist Teaching Behavior Framework

1	Constructivist teachers accept and encourage student autonomy and initiative.
2	Constructivist teachers use raw data and primary sources.
3	When framing tasks constructivist teachers use cognitive terminology such as classify, analyze, predict and create etc.
4	Constructivist teachers allow student responses to drive lessons, shift instructional strategies and alter content.
5	Constructivist teachers inquire about students' understandings of concepts before sharing their own understandings of those concepts.
6	Constructivist teachers encourage students to engage in dialogue, both with the teacher and with one another.
7	Constructivist teachers encourage student inquiry by asking, thoughtful, open-ended questions and encouraging students to ask questions of each other.
8	Constructivist teachers seek elaboration of students' initial responses.
9	Constructivist teachers engage students in experiences that might engender contradictions to their initial hypothesis and then encourage discussion.
10	Constructivist teachers allow waiting time after questions.
11	Constructivist teachers provide time for students to construct relationships and create metaphors.
12	Constructivist teachers nurture students' natural curiosity through frequent use of the learning cycle model.

More recently, strong evidence has been provided that the implementation of Virtual Reality (VR) in engineering education is compatible with the constructivist learning environment (Soliman *et al.*, 2021). Similarly, and based on a systematic literature review of 154 studies related to single-board computers in engineering and computer science education, the support of a constructivist learning environment by single-board computers has been confirmed by Ariza & Baez (2022). Finally, a positive impact on constructivist learning environments has been reported over the last years by applying educational games and simulations (Gamarra, *et al.*, 2022).

TEACHING AND LEARNING EVALUATION - A CONTROLLED EXPERIMENT

The constructivist approach to teaching and learning engineering thermodynamics was evaluated using a controlled experiment which comprised the application of a pre-test post-test control group experiment (Pfahl *et al.*, 2004). The students from each group, the experiment group (A), i.e., those who were taught using the constructivist approach, and the control group (B), i.e., those who were taught using the traditional delivery method of lectures, tutorials and laboratories, had to undertake three tests, one before their respective courses (pre-test) and two after their respective courses, one immediately after the finish of the course and one month later, to assess student learning and also retention of concepts taught. The performance of the two groups were measured using six constructs, with each construct represented by one independent variable. Each dependent variable has the hypothesis:

1. There is a positive learning effect in both groups (A: experimental group, B: control group). That is to say, the post-test scores taken immediately after the course are significantly higher than pre-test scores for each dependent variable.
2. The learning acquired during each course (and tested immediately after each course finished; Post-test1) is shown to be more effective for group A than for group B, either with regard to the performance improvement between the respective pre-tests and post-tests (i.e., the relative learning effect), or with regard to the post-test performance (absolute learning effect). The absolute learning effect is of interest because it may indicate an upper bound of the possible correct answers depending on the method of teaching.
3. Retention of the learning during each course (and tested one month after each course had ended; Post-test2) is shown to be more effective for group A than for group B, either with regard to the performance improvement between the respective pre-tests and post-tests (i.e., the relative learning effect), or with regard to the post-test performance (absolute learning effect).

Consequently, the Null hypotheses are stated as follows:

$H_{0,1}$: There is no difference between Pre-test scores and Post-test1 scores within experimental group (A) and control group (B).
$H_{0,2a}$: There is no difference in relative learning effectiveness between experimental group (A) and control group (B) immediately after the finish of the course.
$H_{0,2b}$: There is no difference in absolute learning effectiveness between experimental group (A) and control group (B) immediately after the finish of the course.
$H_{0,3a}$: There is no difference in relative retention between experimental group (A) and control group (B) using the results of Post-test2 and the Pre-test.
$H_{0,3b}$: There is no difference in relative retention between experimental group (A) and control group (B) using the results of Post-test2 and Post-test1.
$H_{0,3c}$: There is no difference in absolute retention between experimental group (A) and control group (B) using the results of Post-test2.

The design began with the assignment of students to the experimental group (A) and control group (B) using a pairing system based on students' GPA. The aim, during the formation of groups, was to produce teams having as close as possible equal average GPAs, and having within each group a mixed GPA where the GPA range was, as close as possible for each group. It is well recognized that although having homogeneous groups (i.e. the group members having an almost equal GPA) can increase teamwork satisfaction and possibly enhance overall course and learning satisfaction compared with mixed GPA groups, the overriding purpose of the group formation was to be able to compare like with like. This was followed by members of each group completing a pre-test. This measured the performance of the two groups before the delivery of the courses. In all three tests, i.e., the pre-test, the post-test immediately after finishing the course and the post-test one month after finishing the course, the questions were identical, although this was never mentioned to the students. Also, no questions from the tests were ever allowed to be retained by the students.

Due to the fact that an experiment comparing results of the traditional approach with those of the constructivist approach was to be conducted, the implementation, assessment and delivery had certain similarities, to try to avoid possible bias. The contact hours for both approaches were the same although the breakdown of the different teaching methods within each approach did differ. For example, there was much more formal lectures given in the traditional approach and less discussion periods. Both approaches had a lead Instructor (Professor) supported by two teaching assistants full-time. Again, trying to have no bias in the comparison between traditional and constructivist approaches the assessment methods which contributed to a student's grade were very similar and consisted of assignments, lab assignments, major lab reports and various groups activities. There was also a formal mid-term multiple choice test and final examination for each group containing the same questions.

The students were in the 2nd year, second semester of a four-year mechanical engineering course with the number of students in group A, NA = 38, and in group B, NB = 34. The numbers in the group could be considered as small but there is ample evidence in the literature that the numbers can be considered as sufficient, e.g., rule of thumb: at least 30 subjects suggested by (Hauschildt & Hamel, 1978) and the survey results did not change significantly when the sample size became larger than 20 (Zahn, 1993). The uneven group sizes was because two students insisted on being in the constructivist group rather than the traditional group and using the principle that everything was voluntary, this was agreed to. The characteristics for both sets of students are summarized in Table 2.

Table 2. Student personal characteristics

Characteristics			
	Overall Cohort	Group A	Group B
Average age [years]	20.5	20.4	20.6
Percentage female [%]	23	21	25
Engineering major	Mech. Eng.	Mech. Eng.	Mech. Eng.
Preferred learning style [% of students in group]			
Reading with exercise	8	10	6
Lecture	9	11	7
Tutorial	15	16	14
Laboratory	20	23	17
Group work	18	18	18
Individual projects	16	14	18
Group projects	14	8	20
Opinion of most effective learning style [% of students in group]			
Reading with exercise	9	10	8
Lecture	7	9	5
Tutorial	12	12	12
Laboratory	18	19	17
Group work	16	17	15
Individual projects	20	19	21
Group projects	18	14	22

It can be seen from Table 2 that there is a close correlation between the students' preferred learning style and what they thought to be the most effective learning style for them. Also, it could be argued that students do want to be more actively engaged in their learning with possibly the most active learning, that of being in the laboratory, the most popular.

Data collection

Data for the dependent variables (J.1, …, J.4) were collected with the variables' details listed in Table 3.

Table 3. Experimental variables

Dependent variables
J.1 Interest in Engineering Thermodynamics ('Interest')
J.2 General knowledge of Engineering Thermodynamics ('General')
J.3 Knowledge and skills sufficient to solve 'simple' Engineering Thermodynamics problems ('Simple')
J.4 Knowledge and skills sufficient to solve 'difficult' Engineering Thermodynamics problems ('Difficult')

The dependent variables are constructs used to capture aspects of learning provided by the courses and each was measured using five questions. The questions can be characterized as:

J..1 ('Interest'): Questions about personal interest in Engineering Thermodynamics.
J.2 ('General'): Questions to elicit how much students understand the role of Engineering Thermodynamics in the professional engineering area as found today.
J.3 ('Simple'): Technical questions concerning Engineering Thermodynamics that require fairly elementary knowledge and skills.
J.4 ('Difficult'): Technical questions concerning Engineering Thermodynamics that require a much deeper knowledge and skills.

The results for the dependent variable J.1 were found by applying a five-point Likert-style scale (Likert, 1932) with each answer mapped to the value range R = [0, 1]. The values for variables J.2-J.4 are average scores derived from the five questions for each category. Missing answers were marked as incorrect.

RESULTS AND DISCUSSION

The descriptive statistics are summarized in Table 4 where the columns 'Pre-test scores' and Post-test scores showing the calculated values for mean ($\bar{x}$), median (m) and standard deviation (σ) of the raw data collected, and the columns under 'Difference scores' shows the differences between the Post-test1 and pre-test scores, as well as the differences between the Post-test2 and the Post-test1 scores, and, the Post-test2 and pre-test scores. In line with the value range for the average test scores, the difference scores are on a value range R = [0, 1].

Table 4. Scores of dependent variables

	Pre-test scores				Post-test1 scores				Post-test2 scores			
	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4
Group A												
($\bar{x}$)	0.78	0.71	0.40	0.36	0.79	0.86	0.45	0.50	0.79	0.85	0.44	0.50
(m)	0.81	0.65	0.39	0.33	0.83	0.79	0.51	0.41	0.82	0.78	0.49	0.40
(σ)	0.12	0.32	0.27	0.24	0.11	0.24	0.16	0.20	0.12	0.24	0.16	0.19
Group B												
($\bar{x}$)	0.86	0.61	0.46	0.29	0.87	0.67	0.48	0.41	0.86	0.65	0.48	0.41
(m)	0.83	0.63	0.43	0.27	0.86	0.66	0.44	0.31	0.85	0.63	0.44	0.30
(σ)	0.12	0.25	0.20	0.12	0.21	0.19	0.18	0.11	0.21	0.21	0.18	0.12
	Difference scores (Post-test1 - Pre-test)				Difference scores (Post-test2 - Pre-test)				Difference scores (Post-test2 - Post-test1)			
	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4	J.1	J.2	J.3	J.4
Group A												
($\bar{x}$)	0.11	0.15	0.05	0.14	0.01	0.15	0.04	0.14	-0.01	0.00	-0.01	0.00
(m)	0.01	0.14	0.12	0.08	0.01	0.13	0.10	0.07	0.00	-0.01	-0.02	-0.01
(σ)	0.12	0.18	0.22	0.21	0.11	0.18	0.22	0.15	0.11	0.19	0.23	0.20
Group B												
($\bar{x}$)	0.01	0.06	0.02	0.12	0.00	0.05	0.02	0.12	-0.01	-0.02	0.00	0.00
(m)	0.02	0.03	0.01	0.04	0.01	0.00	0.01	0.03	-0.01	-0.02	0.00	-0.01
(σ)	0.10	0.18	0.26	0.18	0.13	0.18	0.27	0.20	0.09	0.19	0.27	0.15

For $H_{0,1}$ and focusing on the experimental (constructivism) group (A) and for the control group (B), Table 5 shows the results when using a one-tailed t-test for dependent samples. Column one, specifies the variable, column two represents the Cohen effect size, d, column three, the degrees of freedom, column four, the t-value of the study, column five, the critical value for the significance value α=0.10 and column six lists the associated p-value (Pfahl *et al.*, 2004). Using the suggestions of Pfahl *et al.* (2004), testing for the normality assumption, analysis to detect outliers and the non-parametric tests of the Wilcoxon and the Mann-Whitney U-test were carried out for the null hypotheses, and it was found that no normal distribution of the variables could be assumed and that all the data lay within the +/-2 standard deviations around the samples' means. The non-parametric tests did not show any difference from the results of the t-tests.

The results show that the Post-test1 scores of J.2 and J.4 are significantly larger than the Pre-test scores for Group (A). with ; whereas only Post-test1 scores of J.4 were significantly larger than the Pre-test scores for Group (B).

These results reflect evidence that general knowledge about Engineering Thermodynamics is more effectively learnt using constructivist principles. Furthermore, both pedagogic approaches, using constructivist principles and using more traditional principles, are suitable to learn effectively knowledge and skills necessary for solving difficult Engineering Thermodynamic problems. Therefore, based on the differences between Post-test1 and Pre-test scores of the variables considered here, constructivist principles constitute a more effective learning approach.

Table 5: Results for ‘post-test1’ versus ‘pre-test’ for groups (A) and (B).

Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
Group (A): Experimental					
J.1	0.09	37	0.41	1.31	0.342
J.2	0.53	37	2.24	1.31	0.057
J.3	0.21	37	0.90	1.31	0.188
J.4	0.65	37	2.83	1.31	0.004
Group (B): Control					
J.1	0.08	33	0.31	1.31	0.379
J.2	0.29	33	1.18	1.31	0.123
J.3	0.12	33	0.48	1.31	0.318
J.4	1.04	33	4.38	1.31	0.000

Following the same approach for the remaining hypotheses $H_{0,2a}$ to $H_{0,3c}$, for $H_{0,2a}$ and based on the difference scores for Post-test1 – Pre-test (Table 4), it was found that the difference scores for J.1 and J.2 are significantly larger for group (A) than for group (B) (Table 6).
These results reflect that constructivist principles lead to a more effective increase in interest in Engineering Thermodynamics and to a more effective learning of general knowledge related to Engineering Thermodynamics, compared with traditional learning approaches.

Table 6: Results for ‘performance improvement’ for group (A) versus group (B).

Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	0.87	71	3.68	1.29	0.000
J.2	0.48	71	2.01	1.29	0.024
J.3	0.10	71	0.43	1.29	0.336
J.4	0.12	71	0.50	1.29	0.310

To test $H_{0,2b}$ and using the absolute results for Post-Test1 (Table 4), it was found that scores of J.2 and J.4 are significantly larger for group (A) than for group (B) (Table 7). The scores of J.1 are significantly larger for group (B) than for group (A).
This means, the absolute learning effectiveness immediately after finishing the course and related to the learning of general knowledge of Engineering Thermodynamics and of knowledge and skills required to solve difficult Engineering Thermodynamic problems, is higher when using constructivist principles. However, different from the previous interpretation of the relative change of interest in Engineering Thermodynamics, the absolute interest in Engineering Thermodynamics is higher when using traditional approaches. This might be related to the effect of an excited lecturer when presenting videos and photographs related to Engineering Thermodynamics. However, general knowledge of Engineering Thermodynamics and knowledge and skills required to solve difficult Engineering Thermodynamic problems, as well as a more pronounced increase in interest in Engineering Thermodynamics when using constructivist principles, are arguably more important than the absolute interest in Engineering Thermodynamics.

Table 7. Results for 'post-test improvement' for group (A) versus group (B). (bracket value means result goes against the hypothesis)

Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	(0.47)	71	2.04	1.29	0.023
J.2	0.84	71	3.55	1.29	0.000
J.3	(0.21)	71	0.88	1.29	0.191
J.4	0.56	71	2.35	1.29	0.011

To test $H_{0,3a}$ and using the difference scores between Post-test2 and Pre-test (Table 4), it was found that the difference scores of J.2 are significantly larger for group (A) than for group (B) (Table 8). To test $H_{0,3b}$, and using the difference scores between Post-test2 and Post-test1 (Table 4), it was found that no significant difference exists between the two groups (Table 8).

Adding to the interpretation of the higher relative learning effectiveness of general knowledge of Engineering Thermodynamics when finishing the course, the results here show that constructivist principles are also leading to a more long-term higher relative learning retention related to learning general knowledge of Engineering Thermodynamics. However, it should be noted that a significant difference regarding relative learning retention was not identified regarding knowledge and skills required to solve simple or difficult Engineering Thermodynamic problems.

Not surprisingly, no significant learning retention took place between Post-test2 and Post-test1 since students were not exposed to learning Engineering Thermodynamics during this period.

Table 8. Results for 'relative retention' for group (A) versus group (B) (bracket value means result goes against the hypothesis)

Using Post-test2 and the Pre-test results					
Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	0.02	71	0.07	1.29	0.472
J.2	0.57	71	2.42	1.29	0.009
J.3	0.07	71	0.03	1.29	0.488
J.4	0.11	71	0.48	1.29	0.317
Using Post-test2 and Post-test1 results					
J.1	0.04	71	0.17	1.29	0.434
J.2	0.08	71	0.33	1.29	0.371
J.3	(0.03)	71	0.12	1.29	0.453
J.4	(0.02)	71	0.07	1.29	0.471

To test $H_{0,3c}$ and using the absolute results for Post-test2 (Table 4), it was found that the scores of J.2 and J.4 are significantly larger for group (A) than for group (B), but the scores of J.1 were significantly larger for group (B) than for group (A) (Table 9).

These results show that the absolute learning retention relate to general knowledge of Engineering Thermodynamics and knowledge and skills required to solve difficult Engineering Thermodynamic problems is higher when using constructivist principles. This confirms the earlier interpretation of the results related to $H_{0,1}$ which were based on the difference between Post-test1 and Pre-test scores. However, confirming the previous interpretation of results related to the absolute Post-test1 scores, a traditional learning approach leads to an absolute higher interest in Engineering Thermodynamics.

Table 9. Results for ‘absolute retention’ for group (A) versus group (B). (bracket value means result goes against the hypothesis)

Using Post-test2 results					
Variable	d	df	t-value	Crit. $t_{0.90}$	p-value
J.1	(0.44)	71	1.91	1.29	0.030
J.2	0.81	71	3.79	1.29	0.000
J.3	(0.25)	71	1.06	1.29	0.146
J.4	0.56	71	1.35	1.29	0.090

Regarding limitations the following can be said. Construct validity of the experiment was ensured by minimizing all influential factors except the different learning approaches. Repeating the same tasks and questions for pre- and post-tests led to a familiarization and maturation effect for the students, but it did not limit experimental validity since it applied to the experimental and the control group. Different levels of motivation or feelings were not observed. The external validity of the findings is given for the perspectives of respondents and scope of this study. Respondents from different socio-economic contexts or a different course content may lead to different results

CONCLUSIONS

Starting with an exposition of common challenges related to learning Engineering Thermodynamics, this study used an experimental approach, including a group of students learning based on constructivist principles, and a control group of students learning based on traditional principles. It was found that students’ personal interest in Engineering Thermodynamics is more effectively increased (i.e. relative learning performance) when using constructivist principles, although the traditional approach led to a larger absolute interest when finishing the course, as well as a larger absolute interest four weeks after finishing the course.

All measures related to learning experiences confirm that students learn general understanding of Engineering Thermodynamics more effectively when using constructivist principles. Interestingly, no significant differences between the learning effectivity of the two learning approaches were found regarding students’ learning of knowledge and skills that are required to solve *simple* Engineering Thermodynamic problems. Finally, regarding students’ learning of knowledge and skills required to solve *difficult* Engineering Thermodynamic problems, constructivist principles led to higher learning effectiveness when considering the relative learning effectiveness within groups (Post-test1 – Pre-test), absolute learning effectiveness when finishing the course, and the absolute retention four weeks after finishing the course. Traditional learning approaches led merely to a significant relative learning (Post-test1 – Pre-test). The findings confirm earlier findings related to active learning in Mathematics for engineering students and leading to better results (Cabo & Klaassen, 2018), and it should encourage engineering educators to incorporate constructivist principles to enhance active learning (CDIO Standard 8) in order to contribute to more sustainable learning of Engineering Thermodynamics.

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ENGAGING STUDENTS ORIENTED TOWARDS USEFULNESS IN A BILDUNG-ORIENTED ENGINEERING EDUCATION

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ABSTRACT

In the context of engineering education, there has been a turn toward seeing the future engineer as an agent in society, resolving perceivingly more complex problems, often in cooperation with representatives from other professions. Simultaneously, this more system-perspective and citizen-oriented turn in engineering education connects the education closer to the idea of Bildung, where students are expected not only to become practitioners of a craft, but also active participants in society. This paper discusses the contentious relationship between the concepts of Bildung and usefulness, where a theoretical discussion contrasting different traditions and forms of Bildung is illuminated by datasets from 1700 1st year bachelor engineering students across four consecutive years and these students' motivations toward Bildung-oriented topics. The students' profession-oriented motivations and orientation toward usefulness suggest that a Bildung-oriented education based on the idea that there is a conflict between usefulness and Bildung will be unsuccessful in motivating these students to engage themselves in society. An education for engineering Bildung should thus be based on integrating the ideas of usefulness into the concept of Bildung.

KEYWORDS

Bildung, Systems perspective, Usefulness, Standards: 1, 2, 4

INTRODUCTION

The relationship between engineering and Bildung has long been contentious, and by some even seen as contrary. According to Sjöström et al. (2017), Wilhelm Von Humboldt maintained that language was the main manifestation of Bildung, and due to his influential position in academia, this led to the dismissal of the natural sciences' contribution to Bildung, for the benefit of the humanities. Towards the end of his influential 1999 book on Bildung, Dietrich Schwanitz e.g. describes two high school sweethearts, Sabine and Torsten who plan to get married after their studies. Sabine goes to Hamburg to study psychology, German, and art history, while Torsten moves to Aachen to study mechanical engineering. While Sabine gains insight into the foundations of communication and the symbolic systems of culture and is transformed as a person, Torsten learns how to build machines. When they meet again after their studies, Sabine thinks Torsten sounds like a Neanderthal and breaks off the engagement (Schwanitz, 1999).

This reflects a view where the practical knowledge of the engineer is presented as the antithesis to Bildung, and as we will see this view is rooted in a deeper view within some traditions of Bildung where notions of utility and usefulness are seen as conflicting with Bildung.

Other traditions, however, see it differently, and within more recent reforms of engineering education in several countries, Bildung-oriented views have been very present.

THEORY

In the context of everyday higher education, the concept of 'usefulness' seems to be associated with the expectation of a certain skill or piece of information to be applicable or relevant in future professional contexts. What is perceived as 'useful' for an engineer is dependent on the perceived roles engineers will have in society. A common perception of the world our engineering students are part of and eventually will enter as professional agents could be described as a social world of complexity, in terms of problems, interests, the pace of change, and consequences, a world which Elmose and Roth (2005) describe as a risk society. This description resonates with recent policy documents on engineering education (UHR, 2020). In this perspective, resolutions to problems are the results of collaboration among professionals from different disciplines – real-world problems are rarely resolved by representatives of one discipline, let alone individual representatives (Grasso, Burkins, Helble, & Martinelli, 2010). This perspective implies that the scope of what is considered useful or relevant for an engineer is extended, which in turn calls for several engineering 'profiles', as described by Kamp and Klaassen (2016). Examples of this extension are ethical, aesthetical, economic, environmental, and sustainable considerations.

To get a better grasp of the concept of Bildung, and where a Bildung for engineers can be positioned, we can look both at different traditions and forms of Bildung from previous scholarship. Bildung is a concept that can be hard to define concisely, but many descriptions connect the term to education making not only professionals who are skilled at their craft but also active and engaged citizens (Adler, 1952; Klafki, 2016), contributing with their professional expertise for the betterment of society. This account of Bildung fits well with the perception of the role of our future engineers. Bildung and an extended notion of usefulness seem to coincide in this perspective. However, this relationship has historically been contentious, as we will discuss below.

Building on previous work by Gustavsson (Gustavsson, 2012, 2014) and Burman (2011) Sjöström et al. (2017) describes five traditions of Bildung: 1) a *classical Bildung* based on the ideas by Willhelm Von Humboldt, which is described as a process where the individual develops through education, 2) an Anglo-American tradition of *liberal education*, where humanism and generalization are central values, often associated with a classical canon of topics, 3) the less academically oriented Scandinavian *folk-Bildung*, which focused on a Bildung for all citizens, not just for the formally educated, 4) a *democratic education*, which also focused on the collective aspect, albeit towards formal schooling, and 5) a *critical-hermeneutic Bildung* or *Allgemeinbildung*, which share similarities with folk-Bildung, i.e., Bildung for all citizens, with an explicit emphasis on Bildung in all human capacities.

One of the first things to notice from this initial summary is a progression from emphasizing Bildung as an individual process of emancipation, to seeing Bildung as a collective process both of emancipation, but also toward the betterment of society. The latter is in line with current ideals within Norwegian engineering education, calling for an engineering education that e.g. "facilitates the interaction between ethics, environment, technology, individual and society" (UHR, 2020, p. 28), and with the expected development of the future of engineering education internationally (Graham, 2018, p. 43).

In addition, we can separate ideas about Bildung in different forms. Wolfgang Klafki, in an influential paper from 1959 (updated in 1979), describes a difference between *material* and *formal* theories of Bildung (Klafki, 2001). The material theories deal with the contents of Bildung, i.e., knowledge and skills. In contrast, the *formal* theories concentrate on the person that is going through a process of Bildung. These two theories can also be connected to the contemporary educational philosophies of essentialism and progressivism, where the former, like material theories of Bildung, are curriculum-oriented, while the latter concentrates on the formation of the student, similar to the formal theories of Bildung. Up against both these two theories, Klafki sets his concept of *categorical* Bildung, in which the individual and the world simultaneously open themselves up to one another (Klafki, 2001, p. 193). Sjõstrõm et.al. (Sjöström et al., 2017) on the other hand complements these two theories with reconstructionism, shifting the focus of a Bildung-oriented education toward the effects a knowledgeable student can have on society through critical citizenship. This is in line with a perspective from Jon Hellesnes, describing Bildung as the process of connecting the professional language to the everyday language, specifically the language of politics (Hellesnes, 1992).

Bildung and utility

Using the framework described above, we can combine the traditions and forms of Bildung as a theoretical framework, while discussing diverging views on Bildung and utility. As described by Sjöström and Eilks (2017), Classical Bildung is primarily concerned with the emancipation of the individual, and can thus be seen as formal Bildung, following Klafki's categorization (Sjöström & Eilks, 2020). As such, classical Bildung does not refer to utility.

The American "Great Books"-tradition is part of the *liberal education* tradition and can be seen as a *material* theory of Bildung. This tradition is deeply connected to the idea of a *canon* – a list of *great books* every educated person should be familiar with (Liedman, 2001) which stands in contrast to vocational competence, and by extension to usefulness.

To the Scandinavian folk-bilders on the other hand, there was no conflict between Bildung and practical vocational knowledge. It was exactly the practical applications that made the natural sciences a popular arena for folk-Bildung. A Norwegian edition of the Swedish "Textbook in the Natural Sciences for Elementary Schools and Elementary School Teachers Seminars" by Nils Johan Berlin sold over 40 000 copies over the first 4 years from 1853 onwards. In comparison, the first complete Norwegian bible translation from 1854 had the first printing of 6000 copies (Roos, 2017). The reason for this popularity was exactly its utility in a general population largely living off and from nature. That the utility from the technical and natural sciences form a gateway and a motivation toward Bildung and learning to read is more important to the folk-bilders than exactly what is read, points to this being a more *formal* tradition of Bildung, using Klafki's terminology.

Bildung and engineering: two conflicting ideas

There have been several attempts to include Bildung in engineering education. One such example comes from Axelsson (2009) who describes the historical development of Bildung-oriented topics in engineering education at Chalmers University, Sweden. Chalmers started by teaching technical subjects with a societal connection (e.g. "Technical knowledge - increased security"), later moved in a more general humanistic Bildung direction, and finally moved toward a system perspective of engineering (p. 230).

The initial development points to two competing perspectives: Should the Bildung aspects of engineering education lead to a general humanistic-social science-oriented Bildung, or should they help to give engineers a system perspective on technology? (Axelsson, 2009, p. 225). This discussion partially mirrors the discussions of the "great books" and the "Scandinavian folk-Bildung" traditions, as the more general Bildung perspective does not imply utility for the engineer, while the system perspective does.

We can thus see a duality in the view on the relation between Bildung and usefulness not only in theories on Bildung but also in the concrete attempts to create a Bildung-oriented engineering education.

Consequences for engineering education

For a Bildung-oriented engineering education to be successful, it must dip into engineering students' existing motivations that are centered around different forms of utility, like the Scandinavian folk-Bildung tradition. This would be in line with the system perspective described at Chalmers (Axelsson, 2009). Such a perspective, being more overarching, can integrate the general Bildung perspectives with the professional utility in a better sense than the more limited technical subjects with societal connection.

Creating a curriculum that at the same time seems useful to students and thus motivates them and makes them open up to the ideas in this curriculum, which then again transforms them and changes them as human beings, parallels the processes from the Scandinavian Folk-Bildung tradition, but also points toward something similar to Klafki's idea of *categorial Bildung* (Klafki, 2001). Integrating this idea of utility would then be a key to success in Bildung-oriented engineering education.

METHOD

The data in this study has been collected from 1st-year bachelor engineering students through an open question on why they have chosen their field of study. It has been collected at the start of the course "Introduction to the engineering profession" from 2019 to 2022, slightly into the students' first semester.

The data consists of open-text responses that vary in length from single-word responses to a few short sentences, and these have been categorized using thematic analysis (Braun & Clarke, 2006). The open-text responses were coded thematically, and the relative frequency of the different themes was then registered quantitatively.

All responses have been collected by the online student response systems iLike (2019-2021) and Mentimeter (2022), in a combination of online or live classes (2019) or online classes (2020-2022). Note that the wording of the question was slightly changed from 2019 to 2020 (to compare with another student group) from "Why do you want to become an engineer?" to "Why do you want to study engineering?". This must be kept in mind when analyzing the data, and in coding it has affected the interpretation of e.g. single-word responses like "interesting" or "cool" when it comes to connecting these to interest to "subject" or to "job". The brevity of each data point also led us to chunk responses into relatively large categories, which contain both explicit and implicit responses which we inferred to pertain to a certain category. This process is described more in detail in the Results section. The wording of the questions did not seem to have any notable effects when coding other themes. Upon examining the data we have decided to include the 2019 data as well as the results align well with those from other years.

RESULTS

Overall, we can see from Table 1, engineering students have a strong interest in both the subject of engineering, but most of all their future profession as engineers. While there is also a significant job-related extrinsic motivation, the theme combining practical, useful, creative, and future-oriented elements (explained below) is of similar strength, however, slightly declining over time.

There is also a strong altruistic motivation among engineering students, which however also has a slight decline over the four years. In addition, we see several less prominent, but recurring forms of motivation registered in Table 1, and described in more detail below.

Table 1. Frequency of coded themes from the answer to "Why do you want to study engineering?" over different years. The frequencies show what proportion of respondents gave responses in line with the different themes.

Year	**2019 (N=427)**	**2020 (N=490)**	**2021 (N=399)**	**2022 (N=384)**	**Total (N=1700)**
Interest subject	.25	.51	.42	.29	.38
Interest job	.40	.32	.55	.55	.44
Intrinsic altruistic	.28	.19	.12	.09	.17
Extrinsic	.34	.35	.26	.35	.33
Previous education	.06	.11	.09	.07	.09
Challenge	.09	.06	.06	.04	.06
Create, develop, build	.33	.19	.23	.15	.22
Useful	.2	.11	.08	.05	.09
Future	.15	.12	.15	.09	.13
Practical	.08	.13	.07	.06	.09
Create+Useful+Practical+Future	.44	.36	.36	.24	.35
Understanding	.03	.01	.04	.02	.02
Varied work	.07	.05	.10	.05	.07

We have separated the students' intrinsic motivation into a category for interest in and enjoyment of the subjects the students are studying, and another for interest in and (perceived) enjoyment from the job or the profession they envision themselves moving into after their education. These two can however sometimes be hard to discern when students simply respond with "interest", "exiting" etc. without explicitly connecting these motivations to either. In addition, we have the category "Intrinsic altruistic" which describes different motivations for contributing to society (typical examples are helping with the climate crisis, developing technology to improve society, etc.).

In categorizing Extrinsic motivations, external consequences of both the education and possible job are included, like status, salary, but also a secure job, "many possibilities", just getting an education or influences from external actors like family.

In categorizing "Previous education", all references to previous education as motivation have been included like experiences of mastering these topics in upper secondary education or viewing engineering as a natural next step after a vocational education, possibly also after a period of employment. One illustrative example of the latter is: "As an electrician, I've been wanting to expand my knowledge by going to uni - so electrical engineering seemed like a great option."

In categorizing "Challenge" both explicit references to wanting to "challenge" oneself are included, but also some more general comments on wishing to develop oneself that allude to challenging.

In categorizing Creating, both references to "creating", "developing", "building", "forming" and some slightly more general references to creativity and shaping are included.

There is naturally some overlap between this category and the "practical", but both the more general references and the development of e.g. computer programs that are not considered as "practical" in a more physical sense, create a difference. On the other hand, in the "practical" theme some references to an education and/or profession that is more practically oriented will not be included in the "creating" category.

In categorizing usefulness, both explicit references to "usefulness" and e.g. descriptions of "problem-solving" have been included.

In the theme "future" references to their education being future-oriented is notable, but other references to the future are also included, including uses of “new” (e.g. creating something new, previously unseen) and similar terms pointing to the future.

In categorizing the theme "practical", both explicit references to practical work and references to creating/developing concrete "things" have been included. Some students emphasize the balance between theory and practice, e.g. “a good mix between theory and practice, I doubt I’ll ever get tired of it”.

In addition, we register all students with responses within the four last categories from an interpretation that these responses are often connected to a certain view of engineering, e.g., creating something practical for the future is useful. This is a relatively common theme in the responses, we can also see that of a total of 599 students who in brief responses have been assigned one of these themes, 250 have had at least one of the others assigned as well.

Examples of students expressing a combination of these motivations can still be brief and compact: “to find solutions to practical and future problems”, “Creating something new and contributing to technological development” etc.

The theme “understanding” mainly consists of a wish to understand (more about) how different technologies or technological objects work.

The theme “varied work” consists to a large part of the idea of a varied future workday, but also the more overarching idea of a multitude of work possibilities. In many responses, this is connected to the lack of this in a current job after vocational education, e.g. “With my vocational degree I am more or less locked to one position, but as an engineer, I can work in many fields.”

DISCUSSION AND RECOMMENDATIONS

There are reasons to be wary of making strong conclusions on development over time in the student group. One element is the slight change in the wording of the question from 2019 to 2020. Another is the change in setting from a mix of online and physical lectures to only online lectures for collecting data. Finally, there was a change in the response system used to collect the data from 2021 to 2022. Although the form of response was identical, the different user interface and experience of the system might still have subtle influences on the students’ responses. Only in 2020 and 2021 have the data thus been collected in a completely identical manner. For these reasons, we will mainly discuss the total results from these four years, where the data are more robust, and not the more subtle changes between years.

Regarding our main topic of utility, we see that despite the decline over the four years, there is a strong overall motivation in engineering students toward the practical, concrete, and useful, including contributing to society both in concrete areas like climate change, but also more generally in contributing to technological development. The idea of something being useful here clearly has a broader impact than the concrete references to usefulness included in the “useful” theme itself. Building, creating, and contributing to technological development is a central motivation for engineering students. This could be used as leverage for integrating Bildung perspectives in engineering education.

The spectrum of expressed motivations among the students does, however, put some restraints on how this can be integrated. In utilizing a definition of Bildung that connects students and their profession to society, we can see that the elements we have to build upon from the students' motivations go from the altruistic "contribute to fighting the climate crisis through developing renewable energy" to the more purely technology-oriented "contributing to developing new technology" to the more generic "problem solving" and to the wish to develop concrete new products and solutions. It should be noted that expressed motivations like "problem-solving" might not bear any reference to society, but rather reflect an intrinsic interest in solving problems. Nevertheless, as resolutions to technological problems are inevitably linked to society, we can utilize the educational context of engineering education to include both intrinsic interest and societal usefulness, thus supporting a systems perspective on Bildung in which utility is an integral part.

We can thus discern a certain taxonomy of utility in students' motivations, from the very concrete useful product, more connected to the colloquial "usefulness" to the more overarching societal perspective which can connect well with a wish to create a Bildung-oriented engineering education. Utility, in one form or another, is thus at the core of engineering students' societal motivations, and an interpretation of Bildung that separates Bildung from utility will be of little relevance to engineering students' existing motivations. One could envision an education attempting to move engineering students upwards in their taxonomy of utility, from building things to contributing to technological development in general toward building and improving society.

As a final note, we will comment on a couple of developments from the results, prominently the decline in altruistic motivations. Could it be that the insecurities from the pandemic and war with consequential economic insecurities have shifted students' focus away from e.g. tackling climate change and more toward securing their future? The extrinsic motivation however seems stable. There is also a decline over time in the "create, develop, build" theme. One could hypothesize that this is a sign of an academization of study programs that until recently were in engineering colleges but then merged into a larger university, away from their practical roots. These data can however not conclude on such questions, but these could be topics relevant for further, more qualitative, studies.

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THE EFFECTS OF LEARNING ENVIRONMENTS ON STUDENT ACTIVE LEARNING

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ABSTRACT

Student active learning has been shown to have a significant positive effect on learning outcomes as experienced by students. The learning environments where these activities take place are often simplified to describe the immediate surroundings during a short-term task. In this study, we have examined the characteristics of active learning environments that have emerged from a long-term culture of student and tutor participation in a mutual development of their surroundings.

We selected 3 technology study programs at the Norwegian University of Science and Technology. These 3 programs have shown a significant positive correlation between learning outcomes and degree of student active learning as experienced by the students over time. We describe the spatial and temporal opportunities for the students to seek out surroundings that support the holistic learning activity at hand based on their own preferences.

We propose that environments that support student active learning in the context of wicked problems are fundamentally different from traditional and active learning spaces. Even though this environment can be established for a short while by a skilled supervisor, developing a long-term spatial response that nurtures a culture of student-active learning focused on wicked problems needs to consider a multitude of parameters that are rarely included in university descriptions of space needs. We show that these spaces are to a certain extent dependent on emergent behavior and resist attempts to govern them, re-create them strategically or to standardize their contents.

Our findings have implications for the design of learning spaces and advocate nurturing active learning social groups as they emerge through culture, rather than a simplified description of special needs in developing learning spaces.

KEYWORDS

Student Active Learning, Learning Environments, Standards: 6, 8

INTRODUCTION

Engineering students are traditionally given well-defined problems with one correct solution, such as calculating the resonance frequency of an L-C circuit or the maximum load of an iron beam. Such problems may be suited for learning about specific physical principles and the ability to conduct sub-tasks in an engineering project. However, the problems students later will face as engineers are much more complex, including for instance access to fresh water and tackling digital crime. These are often referred to as “wicked problems” (Horst W. J. Rittel & Webber, 1973). They have no correct or wrong solution, only better or worse suggested solutions. Also, wicked problems cannot be precisely formulated. Learning and building experience to tackle a wicked problem requires different educational approaches than what many universities offer today. Higher education institutions are therefore increasingly adopting teaching methods where students engage as active participants rather than passive recipients (Englund et al., 2017), thus leaving the traditional classroom teaching behind in favor of more student-active approaches to education. Such approaches include student-driven projects (McDonnell et al., 2007), open-ended case exercises (Solvoll & Haneberg, 2022), and intensive Design-and-build workshops (Aalto & Rintala, 2016), to name a few.

These learning practices require new learning spaces and nonetheless question the relationship between the long-term emergence of teaching cultures in given learning spaces and the short task-related environments that are mostly focused on in current literature. The purpose of this study is to examine an alternative approach to examining learning space characteristics. We propose that an analysis approach previously applied to makerspaces is more suitable to examine characteristics of learning spaces that enable active learning through wicked problems.

THEORY

Students' firsthand experiences are key to their experiential learning (Kolb, 2014). Also, being active and experiencing in an environment with others foster vicarious learning and social learning outcomes (Bandura & Walters, 1977). By being participants in an environment with faculty and more senior students, the students may also learn by being involved in a community of practice (Lave & Wenger, 1991) where students gradually get engaged in practices related to their discipline. Student-active learning approaches – and hence appropriate learning spaces – are essential to experiential and social learning outcomes.

Formal learning environments can be conceptualized and categorized in different ways (Ellis & Goodyear, 2016). A practical conceptualization is that they include people, resources, pedagogy, and spaces, but the contribution of each of these elements to learning outcomes is difficult to separate from the others (Leijon et al., 2022). From a student perspective, a plethora of different learning environments would again constitute a Learning Landscape (Dugdale, 2009), and the varied availability of these learning environments is necessary to support a student-active and student-driven learning process (Leijon et al., 2022). This makes it necessary to distinguish between different learning environments as well as the different constituents of each of those environments. In this study, we build on four previously identified, distinct types of learning environments (Beckers et al., 2015) with distinct characteristics and focus (Beckers et al., 2015; Ellis & Goodyear, 2016) for our discussions:

1. *Behaviorism-based learning environments* that best support teacher-centered processes designed for the acquisition of knowledge and skills. This is typically a

traditional classroom or a lecture hall where the teacher stands on a podium or similar central place.
2. *Cognitivism-based learning environments* that support self-regulated individual studies. These can be either Knowledge Commons or libraries that support concentrated work over a long period of time.
3. *Social Constructivism-based learning environments* that promote student interaction. These include learning how to participate, use tools and dwell in those spaces. This approach to learning is normally found in an Active Learning Classroom (ALC).
4. *Connectivism-based learning environments* where students interact with other students and resources. This might include creating new tools and even building or reconfiguring the learning spaces to suit their needs. These are more informal learning settings that include makerspaces, hackerspaces, architecture or design studios that are student-centric and sometimes also student-driven.

While traditional approaches in higher education bring the benefit of being very predictable and even controllable, student-active learning approaches where students are in charge of their project activities and objectives bring more uncertainty for both faculty and students (Solvoll & Haneberg, 2022). Active Learning Classrooms (ALCs) are the spaces that are specifically designed to accommodate active learning strategies. Together with an active learning pedagogy, engaged teachers and students, as well as teaching resources, they constitute an active learning environment (Leijon et al., 2022). Three recent reviews have explored the current knowledge on ALCs and found the spatial framework of active learning to be under-researched and fragmented (Ellis & Goodyear, 2016; Leijon et al., 2022; Temple et al., 2008). ALCs are by nature polycentric and can be understood through connectedness. This includes increased mobility of participants in the learning situation and increased visual connectedness between participants that nurtures communication and connectedness through tools that promote joint work (Talbert & Mor-Avi, 2019). The tools included in the space can be further divided into objects, artefacts, tolls and texts (Ellis & Goodyear, 2016). While many of the studies talk about the architecture of the space, the focus is mostly on the services and furniture layers of the building (Brand, 1994; Wang & Han, 2021). These layers have limited lifespans and can be altered quite easily in the building. Especially movable furniture is mentioned often.

However, ALCs must still be understood as formal learning environments that follow a teacher-led progression and framework. This is in contrast to (1) the more student-centric studios that are used in architecture, design and entrepreneurial education where the students are often encouraged to alter their surroundings to fit their learning needs, (2) makerspaces and hackerspaces where students gather to explore in a semi-informal setting, as well as (3) different types of labs that allow the students to explore (often physical and digital) solutions to problems and get feedback from both teachers, fellow students and from fast experiments. Makerspaces are currently not well defined (Mersand, 2021) but caution has also been advised to define it too strictly as the concept is still new (Mersand, 2021; Vossoughi & Bevan, 2014). Makerspaces are characterized by several learning activities taking place at the same time, interdisciplinarity and cross-pollination (Mersand, 2021). In contrast to active learning environments, makerspaces have 6 dimensions that define outcomes (both learning and other): tools, objectives, participants (including facilitators), rules, community and division of labor (Mersand, 2021). A notable effect relevant to our study is social scaffolding, a culture of helping each other and working together while asking questions (Bevan et al., 2015).

A makerspace as a physical space is considered a creative space that both has distinct functions (personal, collaborative, presentation, making and intermission) and qualities (knowledge processing, culture indication, process enabling, social dimension and sources of stimulation) that are suitable to discuss the content and inherent qualities of all physical learning environments (Thoring et al., 2018). A more detailed overview of space types is also possible, but unnecessary for our study (Thoring et al., 2019).

It should be noted that a significant portion of the research on ALCs (Leijon et al., 2022) and Makerspaces (Mersand, 2021) is conducted in USA, which differs from the Nordic higher education.

METHOD

In this study, we use aggregate data from the Norwegian Student Survey (NSS) 2021 (NOKUT, 2021) to examine the students' perception of their study programs. The NSS is a bi-annual survey where enrolled students evaluate their own study program across Norway. The dimensions include social coherence, access to teachers and resources, time use and satisfaction factors. This data is combined with exploratory discussions and observations (photographs and live) to form the basis for a qualitative observational study (Queirós et al., 2017) where the authors also act as informants. This provides an overview of the cultural contextualization in each of the 3 selected study programs. We then provide a suggestion to the research community on what approach might be taken to investigate the proposed elements and effects in multiple learning environments in terms of credibility, transferability, dependability and confirmability (Frambach et al., 2013), specifically, we utilize the categorization proposed by Thoring et al. (2018) to analyze what functions and qualities are available to the students.

Selected study programs

We selected 2 five-year technology study programs and one two year master program from the Norwegian University of Science and Technology (see Table 1) where the two first have shown a significant positive correlation between learning outcome and degree of student active learning as experienced by the students over time (Øien et al., 2022). The last program is designed in its entirety to utilize active learning throughout but accepts students from other bachelor programs where such approaches are not prevalent.

Study program	Code	Description	Number of students
Industrial Design	MTDESIG	Design of physical and digital products, systems, and services	42
Architecture	MAAR	Plan and design buildings, neighborhoods, and cities	80
NTNU School of Entrepreneurship	MxENTRE	Venture Creation Program	40

Table 1: Selected study programs

Systematic observations and discussion groups

Based on the matrix of functions and qualities adapted from Thoring et al. (2018), we conducted exploratory discussions where we strived to describe spatial and temporal opportunities of the students to seek out surroundings that support the holistic learning activity at hand, based on their own preferences. The activities included visits to the learning spaces, photographing or observing both formal and informal learning situations, photographing the physical learning spaces and noting aspects that might affect student learning.

Analysis approach

Based on the matrix and narratives, the authors developed a conceptual overview of the physical learning environments, learning practices and Student Survey responses (see Appendix 1). The joint findings from these overviews were discussed and an explorative qualitative description is offered below and discussed to suggest approaches to future experiments and approaches.

RESULTS

In this section, we first briefly describe the results from the NSS2021, with further key data available in Appendix 1. After this, we present the characteristics of 5 different spaces (personal, collaborative, presentation, making, and intermission spaces). These results are derived from observations that use the categorization proposed by Thoring et al. (2018). For each space type, we describe the common factors and similarities that were identified in all 3 programs and that differ from normal behaviourism or cognitivism-based learning environments. We provide a more thorough description of the individual programs and their spaces in Appendix 2.

NSS2021 Student Survey Results

The students in the three programs come across as hard-working, engaged and inspired. The results show a large amount of collaboration between fellow students and teachers. The students have a good social environment and use an extensive amount of time in self-study compared to teacher-led activities.

Personal Spaces

In our three examined study programs, a personal learning space is the foremost individual adaptation to one's own learning strategy. Essential functions are the capability to receive, process and store information, adapt the working environment with tools and changes to support the acts of exploration and to extend knowledge storage to the realm of inspiration and well-being. This should also include the ability to make things available for discussions or to hide them from sight. The space should be undisturbed while the student is gone as the placement of things and tools seems to be the result of an on-going process of making and evaluating. It seems reasonable to assume that at least a part of students' personal spaces is digital and sharing from digital storages should also be supported in the space.

Collaboration Spaces

Collaboration in the examined programs seems to consist of two dimensions. A core team of 3-6 persons that are engaged in the same project, task or venture, and an activity of Social Scaffolding (Bevan et al., 2015) that marks more fluent connections based on spatial and temporal needs of the core team. This can include both other teams, teachers, or others. The collaboration space is first and foremost a group space for the core team where they can interact freely, invite others to join and share a joint learning experience. These group bases are also important as indicators of culture both over time as pin up wall panels and displays for objects, as well as temporally as presentation spaces that can enhance the intended message to visitors. Not all tasks are done in teams and students can also engage individually when required by the task in hand.

Presentation Spaces

In addition to collaboration spaces, where others can be invited in for two-way discussions, the 3 programs utilize presentation spaces that are more neutral arenas and more focused on one-way communication. They are jointly owned by a larger group, like the study program or class, but have less meaning as identity bearers for the individual core teams. Rather, these spaces are more controlled by the teachers to supply their own inspirational input as both presentations, i.e., lectures, as well as pin up of relevant background materials or display of objects.

Making Spaces

In both design and architecture, making things must be seen as an integral part of learning. Both programs have 24/7 access to multiple areas for physical exploration and prototyping. These spaces can be understood as makerspaces in their own right and come in multiple variations. They can be governed by dedicated employees like workshops, or they can be integrated as parts of the studios where the students themselves govern their surroundings. Interestingly, also a third option exists. These are more indeterminate rooms with equipment that seem to be deemed valuable enough to warrant a room, but safe and cheap enough to not warrant dedicated employees. A good example is the photo room which has a studio lights and a backdrop, a 3D printer room or a forming lab focused on early phase development of architectural concepts. The core concept here seems to be availability rather than control and the acceptance of loss of equipment for the benefit of student activity throughout the day.

Intermission Spaces

When observing the learning situations over time and in between the more or less designed spaces that are related to learning activities, a fabric of “useless” space seems to emerge. These are spaces for mental breaks, quick phone calls and microwave dinners. These intermission spaces can be understood as an interface between the life in the learning environment and the outside life of the student that consists of normal, everyday things happening and the need to organize that into a coherent day-to-day life where studying is only a part of the puzzle.

DISCUSSION

The results show that an examination framework that is more focused on makerspaces (Thoring et al., 2018), can uncover a more nuanced view of ALCs than is currently used in literature. Specifically, we are able to describe both the individual characteristics of the personal, collaboration, presentation, making and intermission spaces and the commonalities between them that is relevant to active learning. To exemplify, movable furniture is mentioned in ALC literature, but not the ability to hide objects from sight, to have the furniture stay put when not using the space nor the role of the furniture as carriers of cultural expressions for an individual or a team. As we move from short sessions to more long-term environments that support students across tasks, courses, and a multitude of collaborations, our findings emphasise the necessity to understand student ownership to their space. The student's ability to adapt their personal and team space to fit their individual and joint learning strategy seems like a core characteristic that should be studied further. Currently, all the spaces examined are "rough", communicating an acceptance to change and adaptation. We believe this is essential. It also highly contrasts the usual "clean" spaces described in campus developments.

When considering the distinct instance of working with wicked problems in ALCs, they seem to require an extraordinary level of engagement from the students. This is in our study evidenced by the amount of time the examined students spend in their learning environment beyond teacher-led activities (see Appendix 1). Based on our observations, learning by working on wicked problems is a multi-day and often multi-week endeavour. Should the students be allowed to adapt their space, the resulting space will likely be affected by the individual students and team's preferences in terms of working and learning, the wicked task at hand, as well as the overarching architectural surrounding that allows for a certain amount of flexibility. The role of the latter is not well understood. Too little flexibility from the architectural space will limit the working methods of the students (i.e. using an traditional auditorium for group work). Similarly, too much flexibility or a poorly designed space might require ad hoc solutions for even the most common occurrences. For instance, not all of the examined open spaces had an area for phone calls, although it is doubtlessly very common for students to use their phone. As a result, the student would have to dash out into a hallway to take the call. To us, this makes sense if one considers a traditional, teacher-led, learning space but should be considered poor design when the architectural space should support wicked learning activities, with phone calls being a natural part of knowledge gathering, networking and discussions.

CONCLUSION

As higher education moves towards a focus on wicked problems, educators and researchers need to better understand the spaces that are required to support such learning activities beyond current traditional and active learning approaches. Our study shows that by utilizing a more nuanced approach, additional layers of meaning can likely be uncovered by relatively easy observation studies and that the results seem to be relevant to discuss the design and utilization of the spaces.

We currently do not understand the characteristics of spaces that support or hinder students' engagement in wicked problem-based learning, nor the relationship between those characteristics, the surrounding architecture, and the actual day-to-day learning processes. To move forward, we must construct scales and constructs to better understand how students perceive their spaces in these situations, as well as a similarly nuanced description of the spaces. We believe that the current ALC descriptions of physical spaces are too vague and therefore hinder the recognition of these characteristics. While this study used a framework designed for makerspaces, we assume neither it nor our methodical approach can identify all potential characteristics across universities, countries, student groups or pedagogical approaches to wicked problems. It is therefore necessary to develop more robust methods that allow us to compare results across studies.

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BIOGRAPHICAL INFORMATION

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APPENDIX

Scores studiebarometert		Master of Technology MxENTRE	Master of Technology MTDESIGN	Master of Architecture MAAR	AVERAGE OF 17 study programmes at NTNU in Master of technology and -architecture.
Teaching	Engaged teachers	4,85	3,61	4,16	3,56
	Student Active Learning	4,92	4,30	4,49	3,34
Supervision	Number of supervisions	4,31	3,50	3,56	3,24
	Getting constructive feedback	4,77	3,78	3,78	3,49
	Discussions w teacher	4,92	3,91	4,19	3,49
	Discussions w fellow students	4,85	4,35	4,31	3,92
Social environment	Social env. among students	4,54	4,57	4,03	4,30
	Professional env. among	4,69	4,09	4,17	4,21
	Between teachers and students	4,92	3,87	4,03	3,70
Physical environment	Teaching spaces	4,69	4,09	3,66	3,86
	Equipment for learning	4,62	4,35	3,09	3,87
	Library	4,69	4,10	4,66	4,28
	IT support systems	4,85	4,00	3,97	4,02
Inspiration	Stimulating study	5,00	4,40	4,59	3,75
	Challenging study	4,83	4,09	4,83	4,60
	Motivating	4,92	4,09	3,97	3,85
Time use in hours per week	Organised learning activities	12,90	11,26	17,45	14,79
	Self-study	41,50	26,84	34,45	27,39
	Paid practice	6,50	3,25	3,79	3,69
	Total	60,90	41,36	55,69	45,87

Study programme: MTDESIGN (Design)

Thoring et al 2018. *Overview of types and qualities of creative spaces.* SPACE TYPE / SPACE QUALITY	Personal Spaces	Collaboration Spaces	Presentation Spaces	Making Spaces	Intermission Spaces
Knowledge processors	Personal tools, storage boxes.	Wall panels for pin-ups, used for comments from others. Poster areas.	Shelving to store and display WIP models.	Workshops.	Shelving to store and display WIP models.
Indicators of culture	Personal workspace.	Personal projects on display in shelves.	Course examples from teachers and other students on walls.	Studio.	Kitchen with fridge and microwave oven.
Process enablers	Personal tools, cabinet.	Group base w 4-6 tables. Computer lab. Rooms and furniture organized for collaboration.	Reconfigurable exhibition space for student work. Screens and projectors in all studios and exhibition area.	Workshop, bad kitchenette, photo room, electronics lab.	——
Social Dimensions	Hallways, small rooms and a photo booth for personal calls.	Group base w 4-6 tables. Rooms for scheduled or ad-hoc meetings. Staff lunch area available outside lunch hours. Student society office.	Exhibition space with long tables for breaks and group work.	Group base.	Sofa group.
Sources of stimulation	Workspaces for individual work at workshops.	Large whiteboards and blackboards in studios.	Wall panels for pin-ups.	Entire studio.	Form models from other students.

MTDESIG: Students and faculty at this program are located in a separate building. Student from each year have their own workspace of 1,2x1 meters in a studio shared with 35-45 students. Teaching is also done in the studios. In addition, the students have access to a number of learning spaces: (1) a combined exhibition and social space where students across the different study years meet, supporting learning between students, (2) a 24-hours workshop with equipment for textile, electronics, rapid prototyping and photo, (3) a wood, metal and plastics workshop well equipped with professional grade machines, (4) a number of rooms and spaces where they can do group work, (4) a kitchenette where they can make hot meals. The students are expected to learn how to use all the spaces and machinery during the first year of studies.

At MTDESIG the students learn both design and engineering. During their studies they have no exams in the design part of their studies. However, they have several exams in the engineering part of their studies. Most of the design courses are group work. The layout and placement of the learning spaces allows for learning across the different study years and creates a short distance between students and faculty.

Photos by Nils Henrik Stensrud.

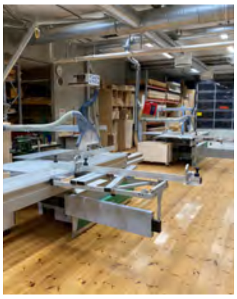
Scores "Studiebarometeret" for Industrial Design Engeneering								
Teaching	Engaged teachers	**3,61**	Student Active Learning	**4,30**				
Supervision	Number of supervisions	**3,50**	Getting constructive feedback	**3,78**	Discussions w/ teacher	**3,91**	Discussions w/ fellow students	**4,35**
Social environment	Social env. among students	**4,57**	Professional env. among students	**4,09**	Between teachers and students	**3,87**		
Physical environment	Teaching spaces	**4,09**	Equipment for learning	**4,35**	Library	**4,10**	IT support systems	**4,00**
Inspiration	Stimulating study	**4,40**	Challenging study	**4,09**	Motivating	**4,09**		
Time use in hours per week	Organised learning activities	**11,26**	Self-study	**26,84**	Paid practice	**3,25**	Total	**41,36**

Study programme: MAAR (Architecture)

Thoring et al 2018. *Overview of types and qualities of creative spaces.* SPACE QUALITY / SPACE TYPE	Personal Spaces	Collaboration Spaces	Presentation Spaces	Making Spaces	Intermission Spaces
Knowledge processors	Library downstairs.	Wall panels for pin-ups, used for comments from others.	Shelving to store and display WIP models.	Formlab.	Shelving to store and display WIP models.
Indicators of culture	Personal workspace.	Personal projects on display in shelves.	Course examples from teachers on walls.	Group base.	Junk everywhere.
Process enablers	Personal tools, cabinet.	Group base w 4 tables	——	Woodwork shop, bad kitchenette, photo room (junk)	——
Social Dimensions	Hallways for calls.	Group base w 4 tables	——	Group base.	Sofa group, sito, cantina.
Sources of stimulation	Window rows, views.	——	Wall panels for pin-ups.	Entire studio.	Form models from teachers.

MAAR: Students from each year have their own space of approximately 3x1.2 meters in a studio. In the first 3 years, approximately 90-100 students share the same studio space and mainly work in groups of 3-4 students. In the last 2 years, the students are working in smaller groups (15-25 students, depending on selected course) in a smaller studio. The studios are centrally located on campus. The studios are "rough" spaces, as in the students are allowed and encouraged to adapt their physical space to their needs. They also have access to a quiet library close by, a 24-hour model building space with some tools, a idea-development space designed to promote fast iteration of design concepts with small tools and physical modeling, a wood workshop with professional grade furniture making machines and metal workshop and a café/cantine. The students are expected to learn how to use all of the spaces, including woodworking machinery, themselves during the first year of studies. For students that attend corresponding courses, there is access to a daylight lab, wind tunnel, plastics workshop, full scale space lab. The students can learn to use laser cutters, 3D printing, 3-axis CNC machining or a 8-axis robotic milling cell, should they need it in their studies.

The students participate in large amounts of group work throughout their studies. There are only 5 exams during the first 3 years of study as all architectural courses have a project-based submission for evaluation.



Photos by Jörg Siegfried Schauer.

Scores "Studiebarometeret" for Industrial Design Engeneering								
Teaching	Engaged teachers	**4,16**	Student Active Learning	**4,49**				
Supervision	Number of supervisions	**3,56**	Getting constructive feedback	**3,78**	Discussions w/ teacher	**3,19**	Discussions w/ fellow students	**4,31**
Social environment	Social env. among students	**4,03**	Professional env. among students	**4,17**	Between teachers and students	**4,03**		
Physical environment	Teaching spaces	**3,66**	Equipment for learning	**3,09**	Library	**4,66**	IT support systems	**3,97**
Inspiration	Stimulating study	**4,59**	Challenging study	**4,83**	Motivating	**3,97**		
Time use in hours per week	Organised learning activities	**17,45**	Self-study	**34,45**	Paid practice	**3,79**	Total	**55,69**

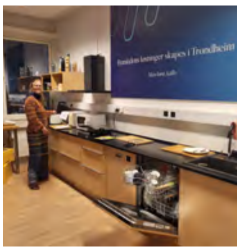
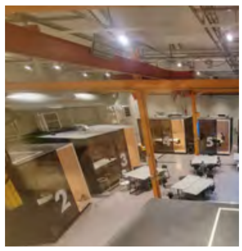
Study programme: MxENTRE (NTNU School of Entepreneurship)

Thoring et al 2018. *Overview of types and qualities of creative spaces.* SPACE TYPE / SPACE QUALITY	Personal Spaces	Collaboration Spaces	Presentation Spaces	Making Spaces	Intermission Spaces
Knowledge processors	Storage of all items related to the start-up.	Awards, prizes, etc. That previous teams have won.	Events that gather and disseminate knowledge in the entrepreneurial ecosystem.	Workshop in same building with basic tools.	Dedicated personal offices to store their products/material.
Indicators of culture	Professional items, such as prototypes, etc. Personal items, incl. Food, clothes, computers, decorations, etc.	Event space 1. floor, and their dedicated office spaces. Some offices are avaliable for meetings.	Flyers, rollups, etc. from student-led activities	Unfinished projects.	Kitchen with fridge, microwave, water-cooler, coffee maker, etc.
Process enablers	Offices for each start-up team	Whiteboards, movable desks and other furniture. Rich selection of markers, paper, etc.	Re-arrangeable tables for rapid adaptation to different situations, such as groupwork vs. lectures.	Tools available to anyone	Self-made posters, banners, exhibition of products from the start-ups.
Social Dimensions	Kitchen/living room, hallways, personalized offices.	Offices with personal equipment, prototypes, tools, etc.	Ping-pong table in the classroom for use in the breaks.	Space for multiple users at once.	Sofas in the hallways.
Sources of stimulation	Teammates and their personal artefacts in the office.	Whiteboards, "roughness" of offices so that they can be altered and re-organized.	Re-arrangeable tables for rapid adaptation to different situations, such as groupwork vs. lectures.	The smell of wood, glue, etc.	"Junk" to play around with during informal conversations.

MxENTRE: Is a venture creation program (VCP) where students create their own start-ups alongside a full curricular program in entrepreneurship. There are 35-40 students in each cohort, and they are located in their own space at campus that is secured by code locks. After testing business ideas during the first semester, students self-organize into start-up teams. Each of the student start-ups have their own designated office space that they can organize and decorate as they wish. The students are encouraged to figure out how to best make use of their office spaces. Also, the students in MxENTRE have their own classroom for internal lectures and seminars, a podcast and media room for recording pitches and marketing material, a large kitchen and living room where meals for the entire day (breakfast, lunch, dinner, etc.) can be prepared.

Each year, the students work intensively for a few days to raise funding from the industry for their coffee, cabin trips, internal parties, kitchen equipment, etc. In the first floor of the same building, MxENTRE students occasionally use seminar rooms and a workshop with basic tools, when needed. Moreover, the students in MxENTRE use the large event-space at Gruva to participate in or host internal events and hackathons, pitching competitions, etc. with externals. MIENTRE is a two-year program where students have first completed at least three years of an integrated engineering degree or a BSc. in engineering (MIENTRE). There are students taking the same program in practice, but with a natural science or social science background (MENTRE). Thus, most courses include interdisciplinary teamwork since the students originate from a wide range of engineering or other backgrounds.



Photos by Dag Håkon Haneberg.

Scores "Studiebarometeret" for Industrial Design Engeneering								
Teaching	Engaged teachers	**4,85**	Student Active Learning	**4,92**				
Supervision	Number of supervisions	**4,31**	Getting constructive feedback	**4,77**	Discussions w/ teacher	**4,92**	Discussions w/ fellow students	**4,85**
Social environment	Social env. among students	**4,54**	Professional env. among students	**4,69**	Between teachers and students	**4,92**		
Physical environment	Teaching spaces	**4,69**	Equipment for learning	**4,62**	Library	**4,69**	IT support systems	**4,85**
Inspiration	Stimulating study	**5,00**	Challenging study	**4,83**	Motivating	**4,92**		
Time use in hours per week	Organised learning activities	**12,90**	Self-study	**41,50**	Paid practice	**6,50**	Total	**60,90**