INTEGRATING INTERDISCIPLINARY EDUCATION IN ARTIFICIAL INTELLIGENCE AND ENGINEERING SYSTEMS CURRICULUM

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ABSTRACT

The Artificial Intelligence and Engineering Systems (AI&ES) is an interdisciplinary master program coordinated by the Electrical Engineering department at the Eindhoven University of Technology (TU/e), the Netherlands. The university has chosen to create an inter-departmental master program on AI&ES as opposed to multiple departmental programs. The goal is to strengthen interdisciplinary education and to educate T- shaped and π-shaper engineers for the future. From a curriculum development perspective, it is relevant to investigate how the AI&ES program integrates interdisciplinary education and what is the effect on students' learning. In this case study we focus on investigating (1) How to design an interdisciplinary curriculum; (2) How to support teachers in designing and integrating interdisciplinary elements in courses and projects. The method for this study follows a design-based and action research approach to create a vision on interdisciplinary education and bring about change in the context of the AI&ES curriculum. A series of workshops (N=3) were organized (1) to generate common knowledge and understanding by collaboratively identifying what the multidisciplinary and interdisciplinary elements are relevant to construct a curriculum line; (2) to support academic teaching staff to reflect upon interdisciplinary research findings to redesign education and enhance improvement of practice. Academic staff were interviewed and focus groups with students were organized to collect information on students' perceptions. Preliminary findings from teachers' interviews show that it is important to create a learning line from awareness to the application of interdisciplinary elements throughout the curriculum. Assignments where students in groups make use of data research and data collection methods from different domains, provided the room to work on open-ended tasks and to reflect on the integration of interdisciplinary education. Differences among teachers lie in the vision on interdisciplinary education and how to apply it in courses.

KEYWORDS

Interdisciplinary education, curriculum development, design-based research, action research, instructional design. Standards: 1, 5, 8, 9

INTRODUCTION

Providing solutions to contemporary problems and preparing for future ones require not only balanced technological innovation but also diversity in the perspectives, methods and procedures to operate in a globalized world (Engineering Education in a Rapidly Changing World, 2016). Technology and engineering are two essential elements that foster the transformation of systems and devices, stimulating innovation and making solutions possible. The numerous challenges worldwide ask for a multistakeholder approach and interdisciplinary knowledge and skills to propose solutions to contemporary energy, environmental, health and societal developments. These problems are oftentimes complex in nature involving technical solutions requiring in-depth knowledge and expertise. Changing the world with new technologies and solving societal problems involves, generally, professionals and engineers who can solve challenges from different perspectives in a comprehensive manner fostering a multistakeholder interaction to critically think and make decisions.

Next to the need of domain specific knowledge and technical skills, other competencies such as collaboration in multidisciplinary or interdisciplinary teams, communication across disciplinary areas or integrated research methods are essential components of the education of the engineers for the future (Meijers & Brok, 2013). Furthermore, challenges to solve the Sustainable Development Goals (SDG) demand an engineer with a broader scope. Generalists with a multidimensional and multidisciplinary approach are progressively demanded opposite to specialists in one knowledge area (Bierema, 2019; Harris, 2009). Collaboration of professionals to understand the challenging aspects of the problem and applying disciplines is increasingly required.

It has been extensively reported in the literature about the benefits of T-shaped and π-shaped engineers who have a multi- and interdisciplinary thinking approach in the work environments (Kamp, 2016; Bierema, 2019; Demirkan and Spohrer, 2015) as innovators with an adaptive capacity to face other challenges, to quickly learn new methods to operate in complex tasks, and to be flexible to translate knowledge into practical application by working in multifunctional or multicultural contexts. The focus remains, therefore, to not only gain deep and technical skills, but also attributes such as "*the capacity to integrate knowledge of two or more disciplines to produce a cognitive advancement in ways that would have been impossible or unlikely through single disciplinary means",* Spelt (2009).

In line with these thoughts, preparing the engineers for the future to address interdisciplinary challenges in interdisciplinary teams becomes essential as relevant interdisciplinary knowledge domain needs to be integrated in collaboration with other disciplinary domains (Adams, 2007; Schmidt et al., 2012). Therefore, interdisciplinary thinking and the approach to integrating it in education is essential to design an interdisciplinary curriculum in engineering programs. However, there is not a fixed recipe to design a curriculum with an increased complexity from multi- to interdisciplinary and transdisciplinary.

This case study is part of a larger research. In this case study we focus on investigating how to support teachers in designing and integrating interdisciplinary elements in courses and projects. The purpose of this study is, therefore, to present a suitable approach towards constructing an interdisciplinary curriculum aiming at deploying interdisciplinary thinking, in a participatory manner together with management, teaching staff, educational experts and researchers with educational background. Furthermore, the motivation behind this research set up was to support the management of the AI&ES master program to create a shared vision on multi- and interdisciplinary education. The overall goal is to improve educational practice. In the conclusions, we also reflect on how our study and findings align with the CDIO framework and more specifically with standards 1, 5, 8, 9 that focus on the context, design-implement experiences, active learning and enhancement of faculty competence, respectively

THEORETICAL BACKGROUND

Interdisciplinary education has gained lately increasing attention to educate engineers to solve complex challenges. Despite the different definitions on multidisciplinary, interdisciplinary and transdisciplinary that abound in the literature, there is a divergent factor in all these terms thus the interaction and level of integration of knowledge between disciplines. The underlying nuance, therefore, is that students working in interdisciplinary teams learn to integrate domain disciplines with the use of different methods and processes differing from those monodisciplinary contexts (McNair, Newswander, Boden, & Borrego, 2011).

Furthermore, studies on multidisciplinary and interdisciplinary education make emphasis on the need to have a framework upon which to design a curriculum and make explicit the progression from mono- to multi- and to interdisciplinary and transdisciplinary education.

Complexity and the integrative character of the tasks within an assignment, project or product (Klein, 2005) are the building blocks where learning of disciplines and specific competences takes place (Gresnigt, Taconis, Van Keulen, Gravemeijer, & Baartman, 2014) in real-life settings.

For the purpose of this study and relying on the literature on interdisciplinary education, the conceptual framework applied is based on interdisciplinary thinking (Spelt, 2015; Figure 1). This framework consists of an approach to use the constructive alignment theory (Biggs & Tang, 2011) in interdisciplinary thinking which identify design criteria for interdisciplinary learning environments and teaching and learning aspects that may need to be taken into account in engineering education (EE). Furthermore, this conceptual framework includes the learning processes and sub-skills to be learnt by engineering students, making emphasis on the *teaching-focus as well as the learning-focus (e.g.* 'content, 'incentive', and 'interaction') (Spelt, 2015). This validated framework provides insights for the redesign of courses or projects with interdisciplinary components.

RESEARCH SCOPE AND INTERVENTIONS

Design-based research (Joseph, 2004) was used as a suitable methodology as we aimed to design interventions with a pedagogical innovation perspective. Design-based research is a methodology designed by and for educators that aims to advance the impact, transfer, and translation of education research into practice. It emphasizes the need for theory building and development of design principles that guide, inform, and improve both practice and research in educational contexts. In our study, the rationale behind applying Design-based research as methodology is to explore empirically and bring about insights into the practice of multi- and interdisciplinary thinking education in the context of the AI&ES program.

Phases	Phase 1:Plan	Phase 2: Design/Implement	Phase 3:Evaluation	Phase 4:Reflect
Phase description	Phase 1 addresses three key areas: the problem, the literature review and practitioners' experiences.	Phase 2 of the design research approach focuses on designing and developing multi/interdisciplinary elements for specific courses	Phase 3 focuses on the implementation of design elements	Phase 4 focuses on deriving lessons learned from the implementation and dissemination of outcomes to broader educational community

Figure 1. The process of Design-based research (developed by authors)

The grounded principle is to bottom-up construct the framework for interdisciplinary thinking and education within the AI&ES master program. It was necessary, therefore, to apply an approach that facilitates the construction of a common vision on what multi- and interdisciplinary constitutes in the AI&ES program, to gain inspiration on how to apply it, and finally, to stimulate change based on research findings (Waterman, Tillen, Dickson, & de Koning, 2001). Ultimately, it is essential to learn from the classroom interventions in order to improve practice (McNiff, 2002).

Method and participants

In the intervention, management together with the researchers and education support staff were involved in partnership to change the education process. The involvement of the academic teaching staff had a two-fold aim. Firstly, it was meant to empower and motivate teachers to create own vision and meaning in interdisciplinary education by understanding what it is and how to develop an interdisciplinary curriculum and how apply it in courses. Secondly, by researching multi- and interdisciplinary education in courses, new insights were generated and the application in education was refined in a new cycle. Figure 2 gives an

overview of all phases in the educational intervention we designed and implemented and the participants in every phase. Participants consisted of a representation of the AI&ES management, teaching staff, educational staff and researchers (period September 2022 through January 2023).

Phases	Phase 1:Plan	Phase 2: Design/Implement	Phase 3:Evaluation	Phase 4:Reflect
Phase description	Phase 1 addresses three key areas: the problem, the literature review and practitioners' experiences.	Phase 2 of the design research approach focuses on designing and developing multi/interdisciplinary elements for specific courses	Phase 3 focuses on the implementation of design elements	Phase 4 focuses on deriving lessons learned from the implementation and dissemination of outcomes to broader educational community
Design-based Research activities at curriculum level	1.1 Literature review on muti/interdisciplinarity 1.2 Workshop with teachers (N=5) Aim: To support teacher to envision how multi/interdisciplinarity can be implemented in their courses 1.3 Workshop with students (N=70) Aim: to introduce students to the concept of multi/interdisciplinary			4.1 Workshop with teachers (N=13) Aim: to reflect on lesson learned from implementation and brainstorm new steps with a larger group of teachers 4.2 Workshop with teachers (N= 8) to create an aligned curriculum based on multidisciplinary principles
Design-based Research activities at course/project level		2.1 Implementation Implementation of multi/interdisciplinary elements in two master courses	3.1 Interviews with teachers (N=2) Aim: to collect teachers' experiences with designing and implementing multi/interdisciplinary elements in their courses 3.2 Interviews with students (N=7) Aim: to collect students' experiences with multi/interdisciplinary elements in their courses	

Figure 2. Overview research methods and participants (developed by authors)

The intervention at AI&ES consisted of four phases. An initial workshop (*Plan*) on multidisciplinary and interdisciplinary thinking education and competencies, which took place with the overall goal of envisioning how this could be included in courses. This phase led to carry out the first experiments in two courses, namely, *Data acquisition and analysis* and *Human and ethical aspects of AI* in which several elements of multidisciplinary education (e.g. collaboration, reflection, data collection methods from different disciplines, etc.) were included. In addition, an introductory workshop on multi/interdisciplinarity was given in the kick-off meeting of the master program for all students who were introduced to the concept of multidisciplinarity. Consequently, themultidisciplinary elements were implemented in the above-mentioned courses (*Implement*). After the conclusion of both courses, data collection was conducted in the form of interviews and focus groups with teachers and students' to investigate their experiences with the implementation of multidisciplinarity (*Evaluate*). Finally, a workshop was organized with management, academic teaching staff, educational advisors and researchers (*Reflect*) to review the findings of the first experiments and to learn from effects derived from classroom practices (*Reflection-on-action*; Schön, 1984). After this workshop a second workshop was organised where teachers had to identify which multi- and interdisciplinary elements they already use in their course and projects and align them in a learning line throughout the curriculum.

Data collection

Interviews were conducted N=2 with academic teaching staff of the two first courses in the AI&ES curriculum included in this experiment where multidisciplinary elements were integrated (*Act*). The purpose was to collect first insights on how the multidisciplinary elements were included and the preliminary effects observed by the teachers. In addition, focus groups were organized N= 7 students to gather information on perceived multi- and interdisciplinary learning.

RESULTS

Below we elaborate firstly on our experience on how to design an interdisciplinary curriculum (research question 1) and on how teachers and students reflected on the implementation of multidisciplinary elements in the two examined courses and the most important lessons learned (research question 2).

To answer research question 1. How to design an interdisciplinary curriculum we draw on reflections by the researchers based on observations after conducting a series of workshops aimed at fostering awareness of important of multi and interdisciplinarity and supporting in the development of an integrated curriculum. To effectively develop an interdisciplinary curriculum, it is important to rely in a participatory co-creative construction of the levels of interdisciplinarity throughout the curriculum embedded in a vision and in the different aspects of the instructional design of the AI&ES program and courses (Van den Akker, 2003).

Dilemmas that arise when designing an interdisciplinary curriculum were related to making explicit the definition of multi- and interdisciplinary elements such as communication and collaboration. This is an essential part in order to develop a curriculum line with increasing complexity and growth from multidisciplinary to interdisciplinary. Another experienced challenge for teachers was how to integrate knowledge from different disciplines in a certain way that promotes interdisciplinary knowledge acquisition and application.

Teachers also commented on the importance of introducing reflection in a more prominent and integrated approach within the courses and across the curriculum to provide students with tools to learn how to learn.

Finally, to achieve a successful experience of a shared design of an interdisciplinary curriculum, the management team needs to support bottom-up this process. This can be guaranteed by the commitment from both management and teaching staff to engage together in a design-based research approach, where results are used iteratively to gains insights on good practices and guide the further steps in the process.

Regarding the second research question “how to support teachers in designing and integrating interdisciplinary elements in courses and projects”, Table 1 provides some examples of design elements implemented in the two master courses which were the focus of the case study. The two teachers strived to achieve a constructive alignment between learning objectives, teaching and learning activities and assessment.

Table 1. Teachers’ perspective on implementation of multi- & interdisciplinary implemented

Courses	**Constructive alignment**	**Multi- & Interdisciplinary thinking elements in education**
Data acquisition and analysis	Learning Outcomes	• Awareness creation
	Teaching & Learning activities	• Assignments where different disciplines and domain-driven approaches are part of the problem to solve: Students come up with solutions that cover many aspects. Technical and non-technical requirements (e.g., improve obtaining consent, confidentiality, defining data elements, writing research protocols, etc.). • Application domain is from another discipline(s) beyond computer science. Legislation regarding

		humans related data, privacy issues and it means for data collection.
	Assessment	• Feedback is facilitated through discussions. • Reflection on multi-inter elements rather than assessing.
Human and ethical aspects of AI	Learning Outcomes	• (Some) Reflection on multidisciplinary explicitly to develop a higher order of awareness. • Argumentation including empirical and technical premises (integration different disciplines, i.e. ethics, AI in providing arguments).
	Teaching & Learning activities	• Ethical issues with societal relevance by reasoning on persuasive arguments. • Consultation with stakeholders using an appropriate method. • Collect requirements to select a reasonable and innovative design from a perspective that includes societal actors, stakeholders, e.g. introduction stakeholder diagram affected by the implementation of an AI system. • Scheme for ethical argumentation, e.g. Universal Declaration of Human Rights to use through documents; Belmont report with bioethics principles in high level expert group. • Deep learning techniques, artificial intelligence to construct an argument on what is relevant, and use of AI technologies and systems. • Students start with the premise equal treatment under the law, e.g. AI systems promote equal treatment under the law because they can abstract from human biases in helping judges; Legal authorities to make fair decisions or that they go against that because they can be weaponized by the state; Using algorithms for the tax fraud; Human technology interaction, etc. • Combine ethical premises with knowledge of AI as subject matter about how to use algorithms. • Learn how to make positive and negative conclusions about how things should be done; how to deal with uncertainty of real-world situations. • Look at other students' written assignments to make criticism of the argumentation. • Using scientific sources for any empirical claims and putting arguments about how AI should be used to create sound arguments, valid and plausible.
	Assessment	Quizzes and assignments for each of the tutorials to turn in arguments using ethical premises.

Teachers' perspective

Findings from teachers' interviews prompt the importance of explicitly addressing multidisciplinary and interdisciplinary competencies in classroom practices. Thus, collaboration is encouraged through teamwork activities, reflection, and critical thinking through the assignments in which students analyze information, take different perspectives and make decisions.

From teachers' perspective, the effects of the differences in the level of application and integration of multi- and interdisciplinary elements and competencies in a course are different. While in *Data acquisition and analysis* course awareness on multidisciplinary is central to the learning and teaching activities, for *Human Interaction and Ethics* these elements are imbedded in the nature of the discipline and in the learning outcomes. Thus, learning to provide critical arguments with the use of premises implies a broad synthesis and reasoning of the topic in question in which the grounding and justification of any decision implies a in-depth analysis of different disciplines (i.e. law, ethics, AI, algorithms, bio principles, etc.) and the intertwining of those in the case to explore.

Students' perspective

Students appreciated multi/interdisciplinarity as an element of the master. According to students AI is a theme that requires multidisciplinarity. They identified multidisciplinarity being implemented at two levels. First at the level of content courses such as ethics by asking students to consider multiple perspectives and integrate knowledge from different disciplines. At the level of collaboration, the courses asked students to collaborate in common assignments with students from different disciplinary backgrounds and reach shared conclusions and prepare reports.

Students see multidisciplinary as a key element of real-life practice and appreciate elements in education not only at a course but also at a project level.

Table 2. Students' perspective on implementation of multi- & interdisciplinary implemented

Courses	**Constructive alignment**	**Multi- & Interdisciplinary thinking elements in education from students' perspective**
Data acquisition and analysis	Learning Outcomes	• Development of awareness of the importance of multi/interdisciplinarity. • Relevance of multidisciplinarity for real-life practice • Importance of communicating with students from different disciplinary backgrounds and considering their perspectives.
	Teaching & Learning activities	• Multiple steps in handling data and multiple perspectives to consider.
	Assessment	• Multidisciplinarity was not explicitly assessed.
Human and ethical aspects of AI	Learning Outcomes	• Ethics as a good example of multi/interdisciplinarity in AI • Development of awareness of the importance of multi/interdisciplinarity in AI
	Teaching & Learning activities	• Integration of multiple perspectives for development of a shared conclusion and recommendations • Work in multi/interdisciplinary groups
	Assessment	• Final report required integration and presentation of a shared argument developed by a group of students

CONCLUSIONS

The present case study provides an example of how to design and implement interdisciplinarity at a curriculum level and the series of steps that need to be provided to support teachers. Design-based research has proved to be a suitable research methodology that allows for analysis of educational challenges, the definition of common views and reflection to study findings of classroom experiments. Furthermore, it promotes the participation and collaboration of the different stakeholders in education, who are involved to create a common vision and a meaning of what multi- and interdisciplinary elements are for the AI&ES program.

The results of this study are of importance for educational practitioners to illustrate how the CDIO standards can be integrated when developing a new program. Reflecting on CDIO framework, we see that learning outcomes about multidisciplinarity at course level need to be aligned with the vision of program leaders at curriculum level. In our study, the learning outcomes at a course level were discussed, validated together with teachers and the program director. The aim was to introduce students to aspects of multidisciplinarity at the beginning of the master program. Realization of learning outcomes could only be successfully implemented when appropriate pedagogical approaches are used to promote students' active learning on multidisciplinarity. Thus, teachers designed integrated learning experiences to foster students' multidisciplinary thinking with active learning methods. Finally, assessment of learning outcomes should also align with learning outcomes and teaching approaches. This was a point of reflection in one of the courses. The series of workshops illustrates how we can foster faculty competence development to achieve multidisciplinarity at a curriculum level.

Examples of multidisciplinary elements in AI&ES courses are the integration of different data analysis and data collection elements from different domains that students use to solve problems. Also, approaching a challenge from different perspectives implies that students investigate cases and apply insights and theories from other disciplines, e.g. ethics, AI, international law, etc.. The approach of the multidisciplinary courses meets the Intended Learning Outcomes (ILOs) in the instructional design of the course, i.e. to learn criticism and construct arguments and ethical premises, following Biggs & Tang (2011) method on the constructive alignment. Furthermore, it is important to introduce reflection in a more prominent and integrated approach within the courses and across the curriculum.

One general premise is that curriculum development is a co-creation process in which academic staff and researchers are involved to construct bottom-up a vision is a suitable and sustainable approach to develop an interdisciplinary curriculum with increasing complexity throughout the program. To achieve a successful experience of a shared design of an multi- and interdisciplinary curriculum, the management team also needs to support bottom-up this process. This can be guaranteed by the commitment from both management and teaching staff to engage together in a design-based research approach, where results are used iteratively to gain insights on good practices and guide further steps in the process.

In conclusion, collaboration between the AI&ES staff and researchers as a means to co-learn and co-create is the primary aspect of the research process and the key for success in educational change.

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