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).

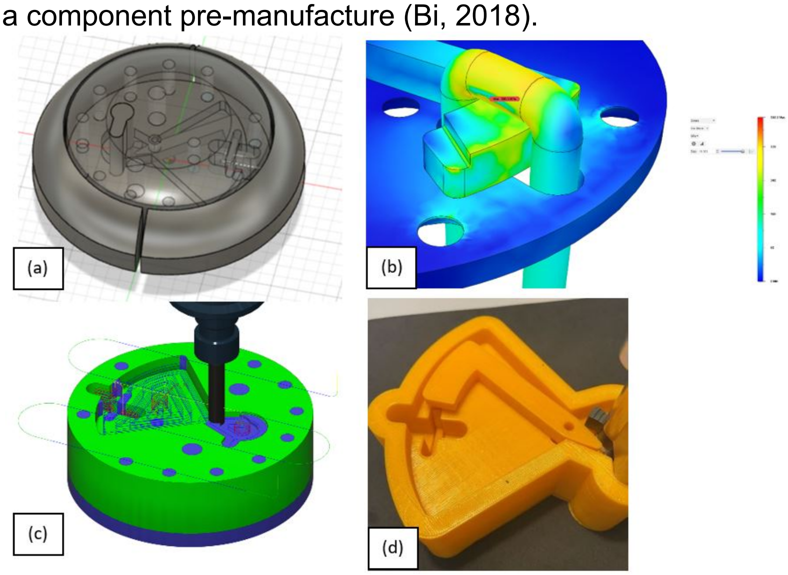

Figure 1: Case Study 1 project outcome: (a) CAD Model, (b) FEA Analysis, (c) CAM Simulation, and (d) Prototype

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).

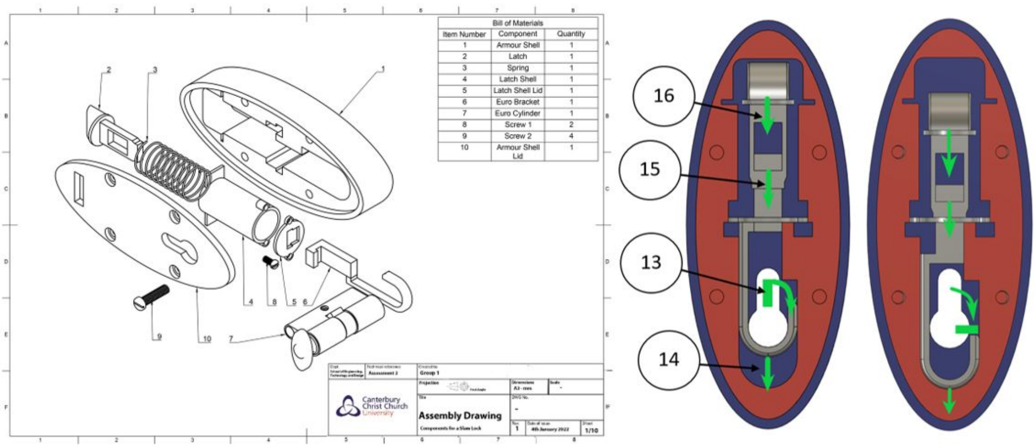

Figure 2: Case Study 2 project technical drawing and latching mechanism

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.

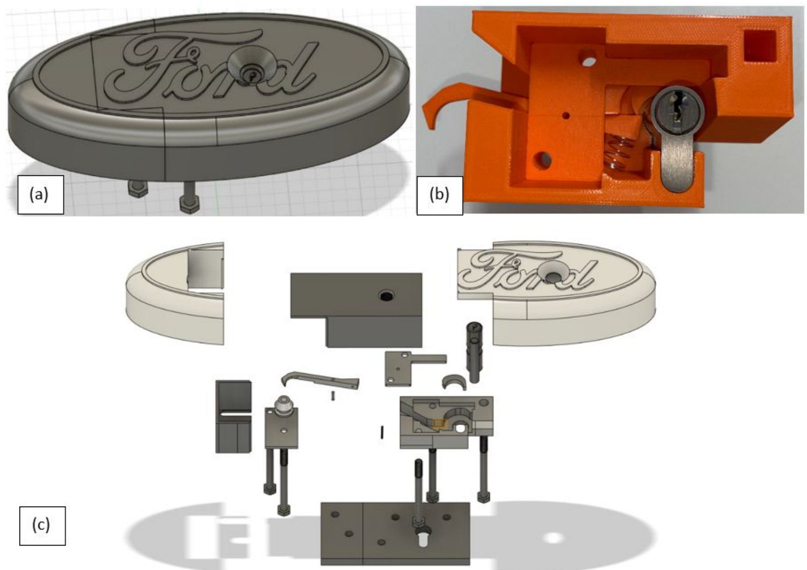

Figure 3: Case Study 3 project outcome: (a) CAD Model, (b) Prototype, (c) Internal Mechanism

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.

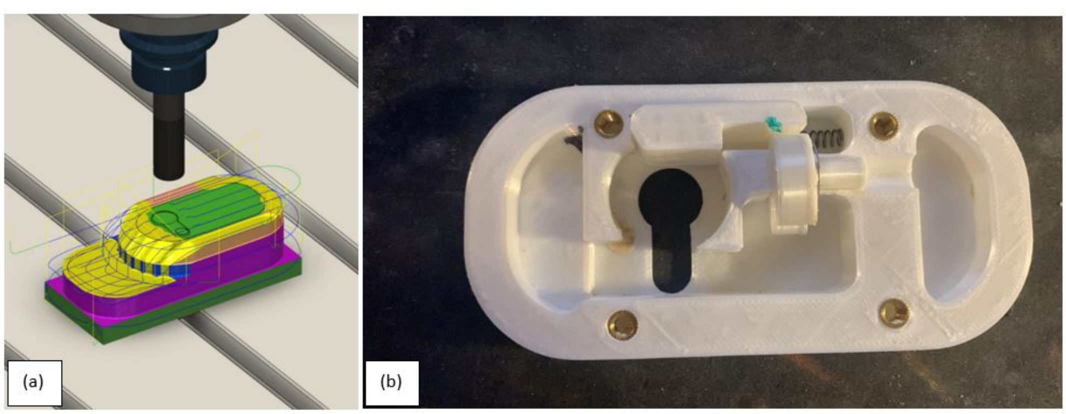

Figure 4: Case Study 4 project outcome: (a) CAM Simulation and (b) Prototype

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 results are as discussed below.

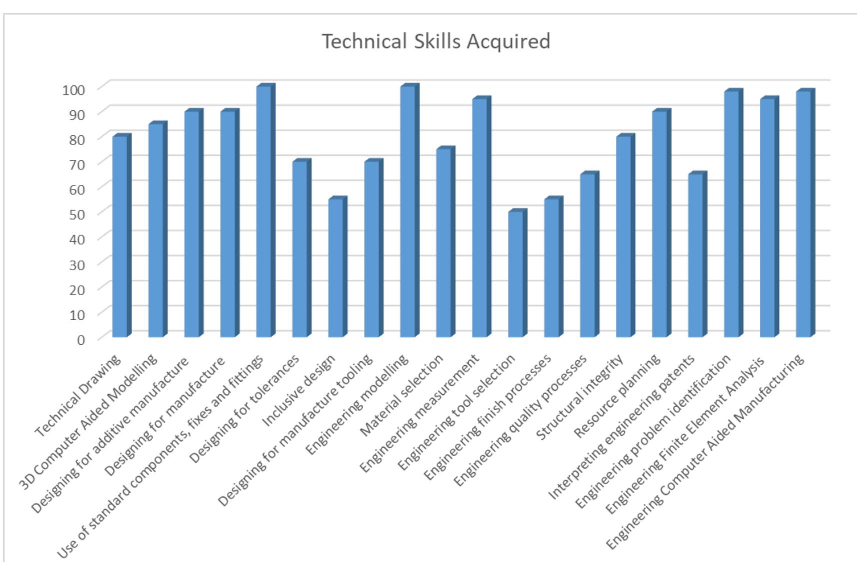

Figure 5: Survey results for technical skills acquired

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.

The graph below shows the employability skills acquired by the end of the module.

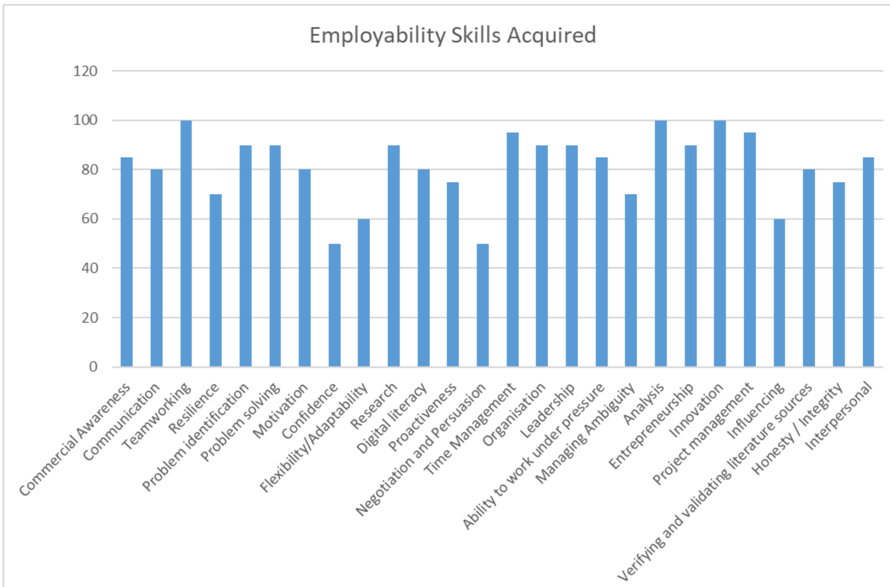

Figure 6: Survey results for employability skills acquired

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).

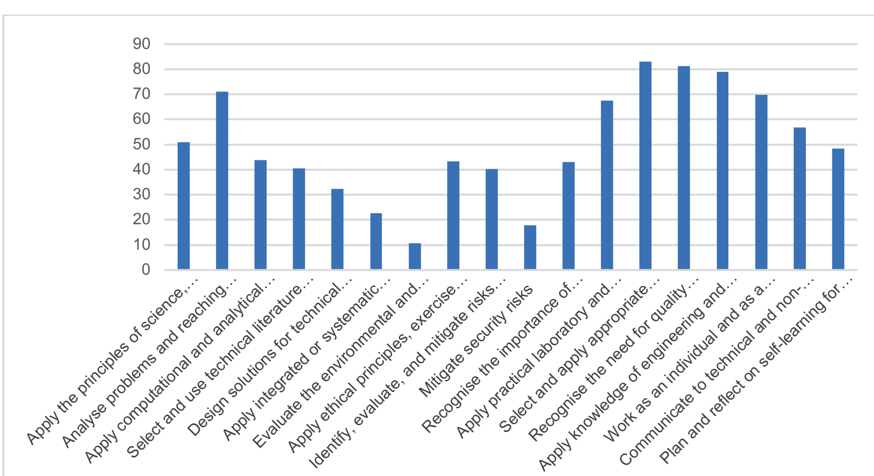

Figure 7: Survey results for other skills acquired

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.

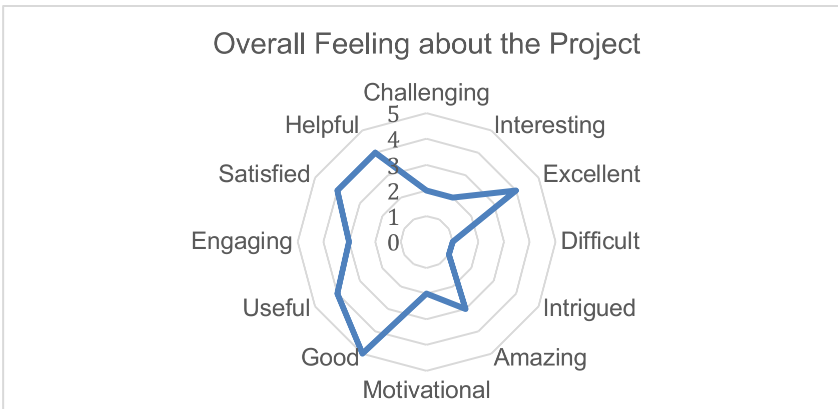

Figure 8: A graph showing the survey results for the overall feeling about the project

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.

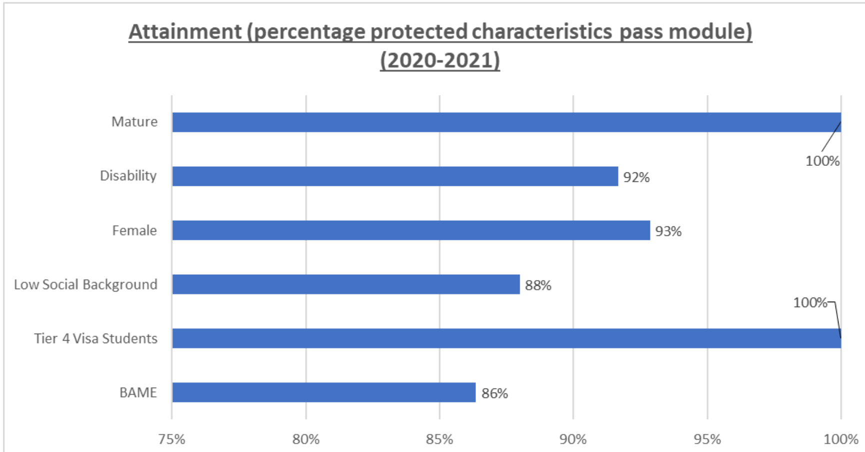

Figure 9: Attainment first-time pass rates for different demographics (2020-2021)

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.

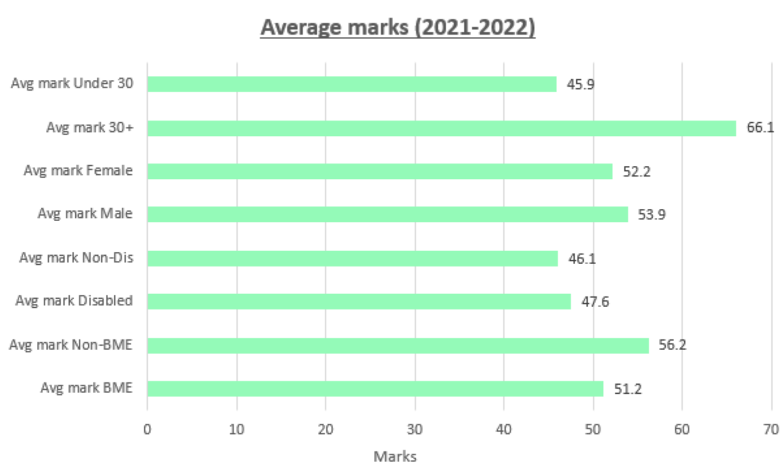

Figure 10: Average marks for different demographics (2021-2022)

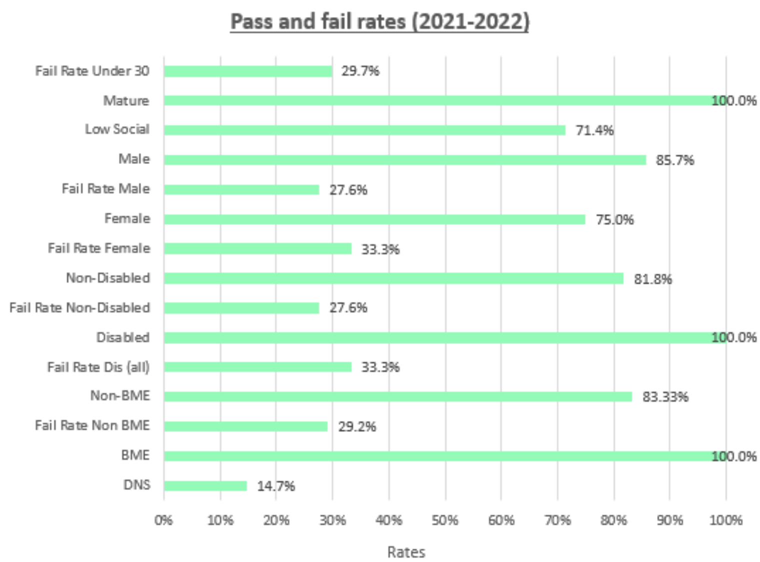

Figure 11: Pass and fail rates for different demographics for 2021-2022

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:

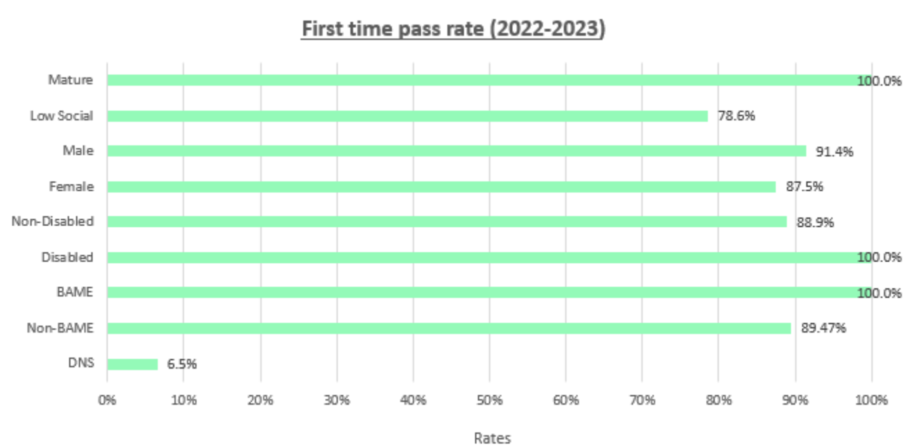

Figure 12: First-time pass rates for different demographics for the 2022-2023 academic year

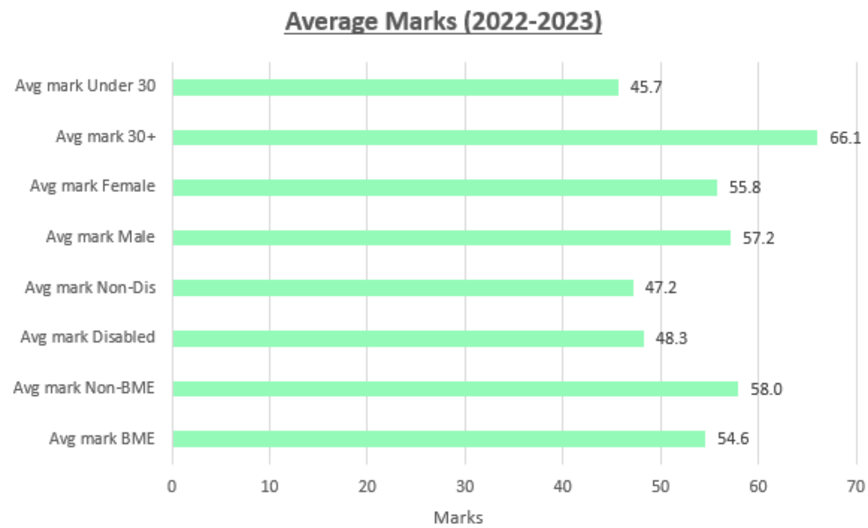

Figure 13: Average marks for different demographics (2022-2023)

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)

BIOGRAPHICAL INFORMATION

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Dr Nikdokht Ghadiminia: is a senior lecturer in Built Environment at the School of Engineering, Technology and Design, Canterbury Christchurch University. She is a researcher and co-author at the IoT Security Foundation (IoTSF) and also part of the leading team in cybersecurity in the built environment working group. She received her Ph.D. in security minded digital transformation in the Built Environment, from Birmingham City University and achieved her BEng and MSc (Hons.) degree in Civil Engineering from the University of Birmingham (UK). As a Chartered Member of the CIOB (MCIOB), Future Leader's CIOB Board Member and a fellow of the higher education academy (FHEA), she is actively involved in research in digital construction, digital twins, BIM, and cybersecurity in the built environment.

Dr Anne Nortcliffe: is Head of the School of Engineering, Design and Technology, Canterbury Christ Church University, UK. Anne has a degree in Chemistry, MSc in Control Engineering, PhD in Process Control Engineering, industrial experience in artificial intelligence and software engineering for the chemical engineering industry. Anne has been an academic in several institutions teaching, leading in areas of automation, manufacturing, computer networks, aerospace/aeronautical, software engineering, software entrepreneurship, mechanical and materials engineering. Anne is an active engineering education researcher with an international reputation in engineering employability development, learning technology to support computing and engineering education, and engineering education pedagogical approaches.

Mr Stuart Lambert: is a Senior Lecturer in Product Design and Course Director of Product Design Engineering at the School of Engineering Technology and Design, Canterbury Christ Church University (CCCU), UK. A member of the Chartered Society of Designers and a Fellow of the Higher Education Academy (FHEA) Stuart has worked as a product designer in London and Milan in design consultancy and as a Design Manager/Director in the manufacturing industry. He now concentrates on researching design methods and techniques at the interface between design, engineering, and educational pedagogy, with particular interest in innovation, manufacturing and sustainability.

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