Embedding Technical and Transferable Competencies in Engineering Education: A Critical Analysis of Curriculum-Level Innovations

Lugg-Widger, Phillip[a] Davies, Aled Wyn[a] Kwan, Alan[a]
Bakthavatchaalam, Venkat[a] Sandford, Richard[a] Hicks, Yulia[a]

[a] School of Engineering, Cardiff University, The Parade, CF24 3AA.

Corresponding Author's Email: Widgerp@cardiff.ac.uk

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ABSTRACT

This contribution explores the integration of transferable competencies and skills at the curriculum level, with a focus on the impact of interdisciplinary engineering and design education through Problem-Based Learning (PBL), but at scale. Adopting a case-study approach, it examines the outcomes of a cross-disciplinary first-year initiative developed at Cardiff University.

Previously, teaching was traditional, predominantly relying on large class lectures, and suffered from poor engagement and higher failure rates. In response, the programme was redesigned to prioritise active learning, encouraging students to think and behave like engineers, while fostering curiosity and problem-solving skills. The new approach emphasises developing emotionally intelligent individuals equipped with engineering skills, rather than producing technically proficient engineers with minimal exposure to "soft skills."

The new structure has only three large modules: Computational, Fundamentals and Applied, covering content across a broad engineering curriculum. The Computational and Fundamental modules scaffold technical knowledge around the Applied year-long module, which was designed to bridge theory with practice. Additionally, the programme introduces a four-block teaching format, and assessment methods were revised to align with the active learning model. These changes have contributed to an increase in student progression rates.

The challenges encountered during the transition from a traditional, lecture-based approach to a more active, competency-driven model are highlighted. It discusses strategies employed to overcome these challenges, including institutional commitment, funding, and curriculum restructuring. Finally, this new approach is critically evaluated, examining outcomes, lessons learned, and serves to assist other institutions wanting to make this transition in their curriculum.

INTRODUCTION / BACKGROUND

Previously, the first year of the engineering program at Cardiff University was split into seven distinct disciplines including: *electrical & electronic engineering, mechanical & electrical engineering, mechanical engineering, medical engineering, architectural engineering, civil engineering and civil & environmental engineering* each with its own variety of 10 and 20 credit modules, the majority of which were single semester. This led to a multifaceted array of student assessments, with overlapping learning outcomes, that were unique for each program and led to progression structures into the second year of study that were overly complex (Mitchell et al 2019). The previous module structure assessed students multiple times for the same technical and transferable competencies across multiple modules for both professional accreditation and educational historical rationale, but the majority of marks came at the end of module examination. A newly implemented first year engineering program and module structure allows for transferable competencies and skills at a curriculum level to be employed whilst exploring problem-based learning scenarios and applied design case studies that are highly applicable to the development of a modern engineer.

AIM AND OBJECTIVES

Overall, the aim of the updated first-year engineering programme was to ensure that core skills and competencies were achieved, with students being awarded sufficient marks to enable progression through these assessments alone. Two synoptic exams were offered at the year-end, to summatively assess the student’s ability to apply knowledge and understanding across the curriculum to given engineering problems.
To achieve this aim, restructuring of the first-year engineering program has been undertaken around the following objectives:

- To arrange pre-existing module content into a simplified structure of three large container modules that span the entire year namely ‘computational’, ‘fundamentals’ and ‘applied’.
- To simplify and unify the structure of the engineering first-year degree calendar across all engineering disciplines into four teaching blocks of six weeks each. In the first five “teaching weeks”, there are no summative assessments, and the sixth week is a dedicated assessment week with no new taught content. This provides students with a regular teaching/assessment scaffolding, and substantial learning periods where students (and attendance) in a module are not “distracted” by an approaching coursework submission or test elsewhere.
- To redevelop the assessment structure with an emphasis on embedding technical and transferable competencies in engineering education, and introduce competency tests for what are actually skills. These will be pass/fail, with a high pass threshold, with multiple attempts being allowed.

- To provide flexible teaching spaces and inter-disciplinary projects that allow students to work collaboratively in class for the application of computational and fundamentals taught material.
- To ensure improved progression rates into the second year of the engineering programs by creating active problem-based learning environments and projects that emotionally intelligent individuals can solve using their developing engineering skillset.
- To prioritise understanding and focus students to solve practical open ended engineering problems, rather than merely an ability to reproduce calculations for standard questions.

PROBLEM AND INTERVENTION

The newly developed first-year for engineering students at Cardiff University restructured the existing 10-20 credit module structure into three year-long modules as shown in Figure 1 retaining the 120-credit system requirement to pass any given year of the program. The three newly developed modules are 'Computational', 'Fundamentals' and 'Applied' which are much larger containers that uniquely spread the soft skill set of an engineer throughout the year developing the engineering mindset and approach as the year progresses (Kek and Huijser 2016).

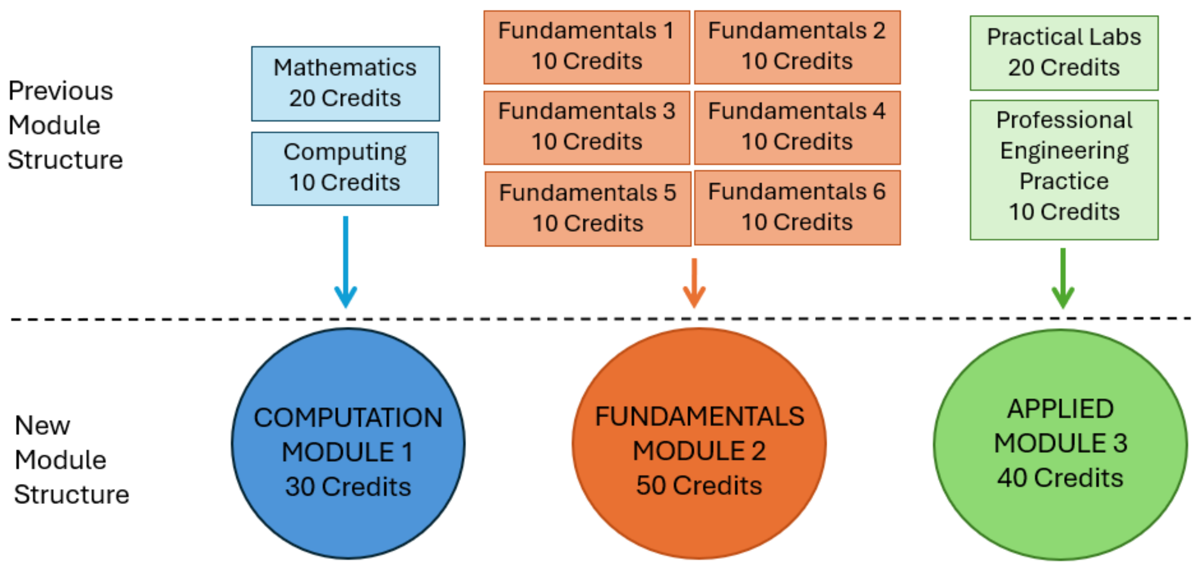

Figure 1: Restructuring of the Year 1 Engineering Program (All disciplines) into 3 modules (Computational, Fundamentals and Applied)

The restructuring and curriculum level innovations (Habbal et al 2024) of the first-year engineering program was developed using the four-block teaching format and assessment methods aligning to the active learning model (Li and Antiohos 2021; Sukackė et al 2022) by transforming the majority of our single semester modules into four blocks of teaching as shown in Figure 2. The six-week blocks are sub-divided into five weeks of teaching followed by one week of assessments at the end of each block. The last week of each block is purely assessment driven typically including two tests from both the 'computational' and 'fundamentals' modules. The week can also include practical laboratory-based assignments from the 'fundamentals' module that forms a competent engineer portfolio at the end of the year. The 'applied' module is assessed through a variety of methods including a written professional practice portfolio based on soft skills and written/video assignments that are both individual and group submissions submitted during assessment weeks. At the end of the year the students participate in final exams for the 'fundamentals' module assessing abilities beyond the minimum competency and a practical showcase demonstrating their incrementally developed case-study and skillset.

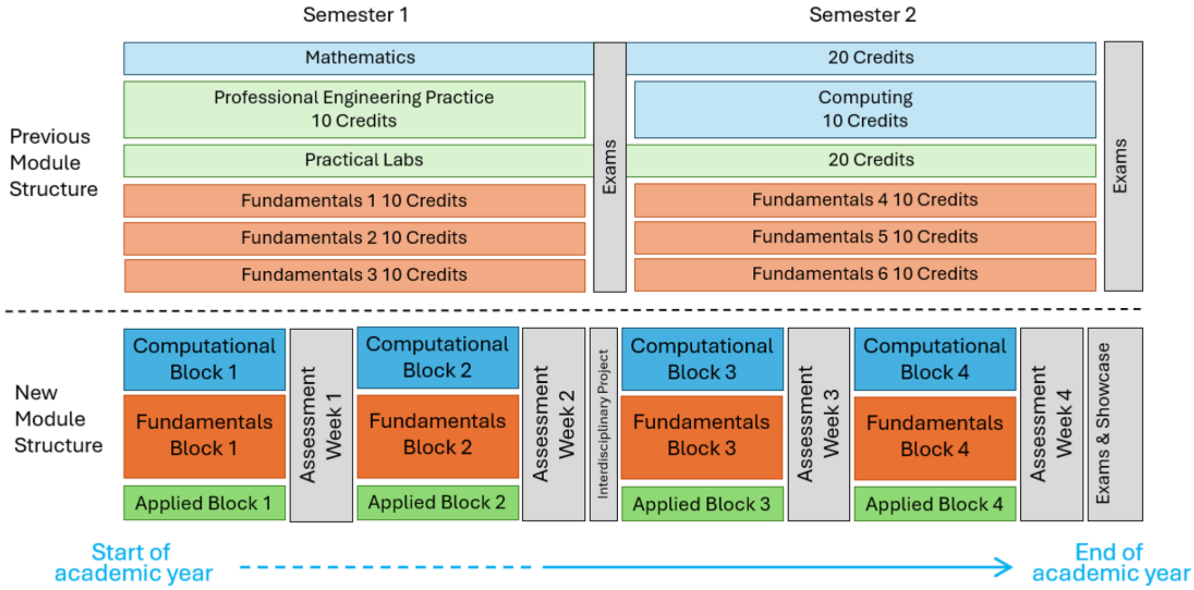

Figure 2: Restructuring of the first-year engineering program from ten conventional single semester modules into three double semester modules with four blocks of teaching

The 'computational' module is comprised of mathematics and computer programming skills that are essential to a modern-day engineer. This module is assessed using individual competency-based assessments. These technical competency assessments, undertaken throughout the year at the individuals own learning rate, allow a student to effectively 'pass' the module at a minimum competent level. The remaining assessments for this 'computational' module are comprised of four tests at the end of each teaching block that assess the student's ability beyond the minimum technical competency level providing an indication of the student's abilities beyond a 'competent' engineer. Mathematics content for this module generally takes the form of flipped learning allowing students to engage with the materials and take competency assessments at their own pace. The computational content is generally taught in-person using computing tutorials that allow for immediate in-person competency assessment and again allow students to engage with materials at their own pace. Mathematics and computation problem-based question sets are taken directly from the engineering concepts taught in the 'fundamentals' module. The mathematical and computational coding skillset is directly applied in the 'fundamentals' and 'applied' modules in an engineering context to solve practical engineering laboratories and increment problem solving behaviours.

The ‘fundamental’ module encompasses traditional technical lectures exploring engineering discipline specific technical abilities whilst applying this knowledge to structured practical and computationally simulated laboratories. The module utilises the mathematical and computational skills as they develop from the ‘computational’ module whilst encouraging ‘fundamental’ discipline specific knowledge to be explored in the ‘applied’ module. The assessment structure for the ‘fundamental’ module is a combination of tests and written assignments based on laboratories that form the ‘technical competency’ level and are undertaken at the end of each teaching block. The remainder of the module is assessed utilising two in-person exams at the end of the year.

The final module is the ‘applied’ module which utilises both ‘computational’ and ‘fundamental’ technical knowledge to solve practical engineering problem-based learning projects (IET 2018). This module is based within a multi-disciplinary flexible environmental where students can interact with both peers and demonstrators to adapt and solve challenges as an engineer. The majority of the ‘applied’ module is based around a year long central engineering case-study that underpins the first-year utilising technical knowledge blocks from the ‘computational’ and ‘fundamentals’ modules and applying it to a single project as knowledge is developed throughout the year. The assessment deliverables from this case study are an individual mid-point video/written report, an end of year group written report and a practical showcase where students demonstrate their uniquely engineered solution to the problem posed at the start of the year. Other aspects of this module include the constant re-enforcement of professional soft skills throughout the year during the PBL case study (Boud and Feletti 2013) and a transferable competency portfolio of the developed skillset. These developing skills are actively applied to a mid-year interdisciplinary project which includes interaction with real-world clients and engineers from industry to create and outline a feasible solution within a given timeframe.

The embedding of both technical and transferable competencies across the three modules is depicted in Figure 3. Figure 3 shows how the technical competencies from both the fundamental and computational modules feed into a central case study of the applied module alongside the transferable competencies also taught in the applied module. The encompassing approach of both technical and transferable skills develops a ‘competent’ engineer that can progress into the second year of the engineering program.

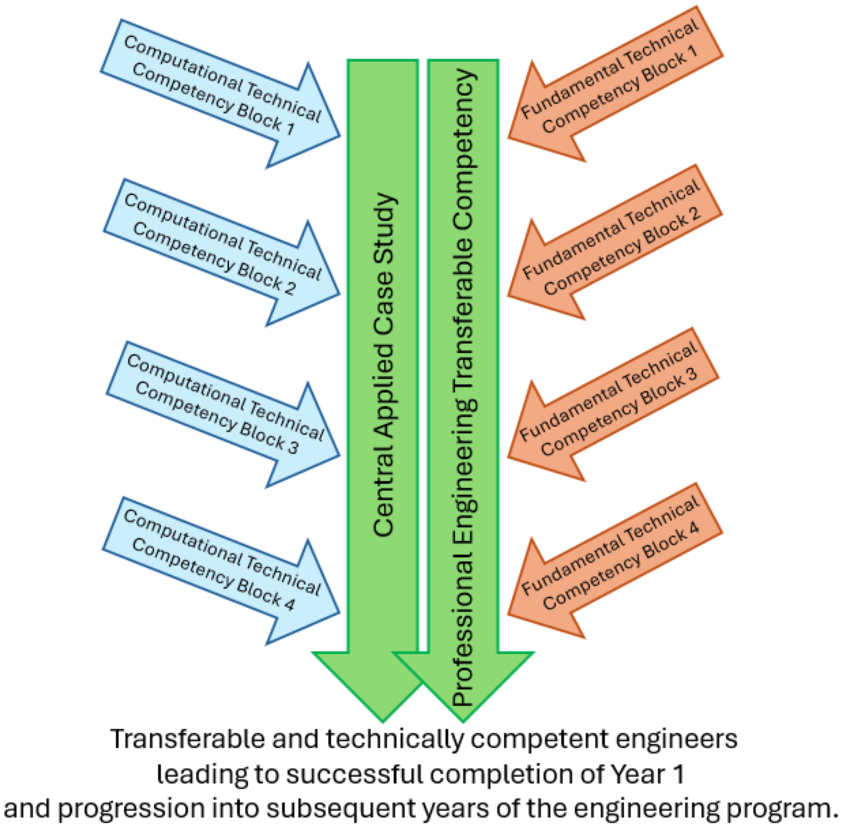

Figure 3: Embedding of technical and transferable competencies in engineering education based around the three 'computational', 'fundamental' and 'applied' modules.

KEY FINDINGS

The restructured first-year engineering program now incorporates new and larger modules, a new block teaching and assessment schedule, problem-based case studies and competency-based assessments. The progression rates for first-year engineering students have improved by 15-20% in the first year of implementation compared to the two previous years.

DISCUSSION / REFLECTION

Having implemented a complete redesign of the first-year engineering program at Cardiff University, the new format has moved from predominantly traditional large lecture classes with poor engagement and higher failure rates to an active learning environment (De Graaff and Kolmos 2007) prioritising and equipping engineers with problem solving skills required to navigate the fast pace of technological advancement. This has led to developing intelligent engineers with the same technical proficiency but increased awareness and professional skillsets.

The four block teaching format introduced within the new module structure of the engineering program has led to increased scaffolding between larger modules and clearly identifies the level of expectation for a 'competent' engineer through competency-based assessments. Furthermore, there are now identifiable links for students to actively engage with PBL (Chen et al 2021) in the 'applied' module through the application of blocks of technical knowledge from the 'computational' and 'fundamentals' modules. Block teaching allows for these new modules to be assessed as content is taught at the end of each six-week block. This means that modules have assessments throughout the year, and the content is not all assessed at the end of the year.

Whilst actively analysing the individual effectiveness of block teaching, setting minimum competencies and increasing focus on transferable skills within this much larger change of course structure, these developments seem to have effectively balanced the proficiency of technical knowledge and the sympathetic transferable skills required for a modern engineer to tackle and solve any problem they encounter (Guerra et al 2017). This new structure effectively overcomes the previous gap in practical application of paper based technical knowledge in the first year.

Advances in tools such as AI have led to some online competency-based assessments and tests being either re-designed to complement full integration of AI tools within the assessment itself or reformatted to an in-person viva or invigilated assessment to ensure assessment integrity is maintained.

As continued transition from traditional lectures to the active model are progressed, we will be further integrating 'fundamentals' content that was traditional paper-based exercises into practical applications-based case-study blocks in the 'applied' module. In order to overcome these challenges of moving from traditional lectures to active learning environments we are fortunate to have institutional support committed to funding new flexible learning environments and spaces. These flexible teaching spaces provide new opportunities for lecturers to encourage and interact with students using problem-based learning case studies in new and exciting ways. This is an iterative process that we are developing as we explore and understand the opportunities for interaction with students in new flexible environments.

The four-block teaching approach is currently in development for the second, third and fourth years for all our engineering programs to extend the approach vertically. Our initial step in subsequent years of the program has been to combine and extend single semester modules so that there are larger container double semester modules similar to our module approach in the first year and simplifying the course structure. Once this has been completed in all years of the program we will be looking to develop and implement the four-block teaching approach for each of the larger double semester modules, however, the added complications of module optionality need to be considered whilst ensuring students complete their degrees with the training necessary for successful and diverse careers.

CONCLUSIONS & RECOMMENDATIONS

This paper introduces the key concepts and recommendations utilised to restructure and conduct curriculum-level innovations in the first-year engineering program at Cardiff

University. Initial progression rates are shown to be encouraging and suggest that implementation of block teaching, module restructuring, flexible teaching environments, problem-based learning case studies and the introduction of technical and transferable competencies have all contributed to improved student progression rates. On-going analysis with supplemental data is required to determine which one or more of these interventions has had the most positive effect on the engineering student cohort. As analysis of innovative curriculum level methodologies progress, further plans to introduce many of these new techniques into subsequent years of study for engineering programs are hoped to increment program progression rates vertically utilising the approaches described for the first year.

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