Project-Based Application Streams to Support Student Motivations and External Engagement

Kim Blackmore, Chris Browne and Jeremy Smith
The Australian National University
Corresponding Author Email: Kim.Blackmore@anu.edu.au

Introduction

In engineering education communities, the importance of project-based learning to prepare students for their graduate careers is well established (Schachterle & Vinter, 1996). Engineering is a complex activity, and degrees that prepare students to become engineers range across many topics, including sciences, mathematics, professional skills, communication, project management, design, and particular technologies (Grimson & Murphy, 2015). Students require non-technical skills to apply maths and science concepts in the context of engineering practice (Froyd & Ohland, 2005). Capstone projects in final year of the engineering degree are a widespread response to this need, but it is very difficult to successfully implement project-based learning in a single course in isolation among students who are used to a traditional lecture-tutorial-lab teaching mode (de Graaff & Kolmos, 2007).

The recently published Australian Council of Engineering Deans (ACED) Engineering Futures 2035 Scoping Study highlights:

> *… the need for organisational structures and cultures that enable and encourage a more humanised/societal focus in engineering education programs; the breaking down of silos to deliver better integrated curricula that contextualise and emphasise development of professional skills delivering a broader range of outcomes; and changes in curriculum context and pedagogies that involve collaborative open–ended problem finding and problem solving in multidisciplinary project teams.* (Crosthwaite, 2019)

State of the art engineering education curricula emphasize student choice, multidisciplinary learning and societal impact, articulated through project-based learning (Graham, 2018). Engineering schools have created designed learning experiences with successive projects, to build project skills progressively through the degree (Frank, Strong, & Sellens, 2011; Kamp, 2013; Venters, Reis, Griffin, & Dixon, 2015).

One response in Australasia has been to develop completely new programs with non-traditional designs. These include Charles Sturt University (CSU) which has four 1-year industry placements after a common 18-month block of topics, modules and content (Lindsay & Morgan, 2016), and the Engineering Practice Academy at Swinburne University of Technology (SUT), where *associates* (the term for students) join a *practice academy* with a variety of externally facing projects throughout their studies (Coddington et al., 2017).

There is also a move towards integrating engineering practice in more established programs, for example at the University of Technology Sydney (Hadgraft, Prior, Lawson, Aubrey, & Jarman, 2016). The ambitious Integrated Engineering Programme at University College London has been implemented across eight departments of a large engineering school with many separately accredited engineering degrees (Mitchell, Nyamapfene, Roach, & Tilley, 2019).

The challenges of undertaking such faculty-wide curriculum reform are significant, and the approaches taken are dependent on the goals, resources and commitments of the institution, and the ambition, values and priorities of the faculty. Effecting change is particularly difficult in the higher education setting due to the persistent and inevitable struggle between academic capital, based on institutional hierarchies, and intellectual capital, based in pan-institutional research communities (Kloot, 2009). Kolmos, Hadgraft and Holgaard identified three strategies for curriculum change employed in engineering schools: an add-on strategy, an integration strategy or a re-building strategy, involving substantial curriculum re-design (Kolmos, Hadgraft, & Holgaard, 2016)

In this paper, we describe a curriculum change based on an integration strategy at an Australian research intensive university. This case study is of a work in progress, with significant internal and external engagement, project-enabling activities (such as the creation of logistics, governance and operational plans) endorsed, and new degree rules in place with courses rolling out over successive years. We offer this program design as a model for a project-based curriculum to the engineering education community to learn from as a case study in curriculum design to accommodate local context.

Context

The existing engineering program at the Australian National University is a single Bachelor of Engineering. Like many engineering degrees, first- and second-year subjects focus on “foundational” sciences and maths, where engineering theory is taught prior to practice, and later-year subjects place more emphasis on engineering domain knowledge and application (King & Male, 2014). All students undertake common introductory subjects and a compulsory systems engineering “core” of approximately 25% of their courses that extends through all years of the degree. This core has a focus on engineering design, analysis, and management. During second year, students select an eight-subject elective major in one of six disciplines: mechatronics, mechanical and material systems, biomedical, renewable energy, photonics, and electronics and communications.

The systems engineering core has long included substantial project-based learning opportunities. In first year, this takes the form of an internal design-build-test style project. Second year can be a mix of content-driven projects and projects with external clients drawn from industry, research centres and the community-sector. Third year often focuses on student-generated projects, building to the development of a business plan and pitch. This sequence culminates in a semester-long group capstone style project and two-semester long individual research project for all students. Capstone group projects have a dedicated client, again drawn from research centres, industry or the community-sector, while individual projects are more commonly proposed by university staff and link to current academic research.

In the existing degree structure, individual projects and topics within courses are set-up and run independently. This provides little continuity for students and a segmented approach for potential external clients: there is virtually no visibility of project topics and options for students until within a course, and little opportunity to take the outcomes from one project and build on that in other courses. From the research presented previously, this does not appear uncommon: even for programs with integrated project spines, there appears to be little planning given to building on project opportunities at each level. The focus is on developing students’ project skills (which are important), through increasingly complex and authentic projects, without building knowledge of the project domains students engage with.

External reviews of the engineering program at the Australian National University, including the most recent Engineers Australia accreditation visit and an independent review of the core by subject-matter experts within the last two years, commend the project-based learning opportunities but highlight the lack of industry engagement across the degree. The School did not wish to completely redevelop the engineering degree or start a new one, so a redevelopment project was commenced focusing on the core. The goal was to design a new system of education in the core of the undergraduate engineering degree that would:

- Increase engagement and interactions;
- Increase program stability, and;
- Enable opportunities for tailorable depth.

An active program of consultation with internal, including students and faculty members within and associated to the degree, and external, including the industry advisory board, alumni and external organisations, stakeholders was undertaken. From this period of engagement, two key (and potentially innovative) ideas were generated which gave rise to the underlying philosophy of the program design:

- During a consultation workshop in 2015 run by two of the authors, current students coalesced around the idea that they would like the opportunity to work on inter-cohort projects: students in early years working with students in later years as part of regular coursework
- During a 2017 presentation to faculty, Geoff McNamara, recipient of the Prime Minister's Prize for Excellence in Science Teaching in Secondary Schools, described his Academic Curriculum Extension (ACE) initiative for project-based science learning at a local high school. He provided his insight that often students are only given a short period of time to learn concepts, and provided an airstrip as an analogy. In this analogy, if, through our curriculum, we only offer a short airport runway for take-off and landing, then we limit our students to flying in small aircraft; if we enable opportunities to create a longer runway, we allow students to ‘take off’ with larger, more challenging projects.

The concept of providing opportunities based on these two ideas—that is, build a long runway through multi-cohort projects—became the basis for the new program design, scaffolded by content that spanned theory and practice.

New program design – a systems approach

Historically within the program, adjustments to the curriculum have been made at the course level, with changes to convenors, learning outcomes and course descriptions. Over time this has created inconsistency in the individual courses, and an incoherent journey for students through the sequence of core courses. In short, such changes at the course level have had little lasting impact.

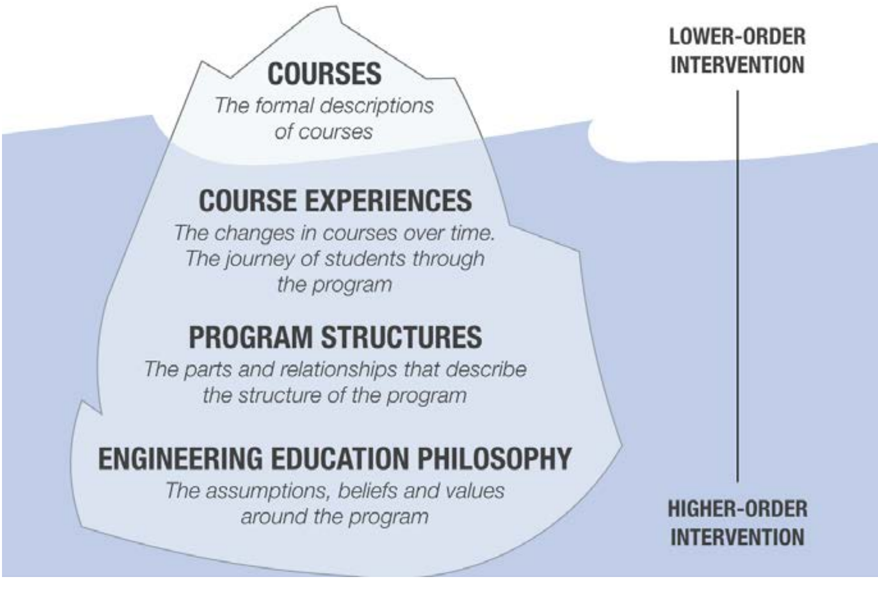

Figure 1: Iceberg model of education programs

To examine this idea further, we have adapted the iceberg model for systems thinking to education program design (NWEI, 2019). This model recognises that the visible part of the system above the water level is only a small part of the system. To understand the whole system, we need to examine the deeper layers of the iceberg.

In this model, shown in Figure 1, courses are the visible part of the system, made up of components such as the formal descriptions, learning outcomes and assessment schemes. Under the surface of the water lies the experiences that are not captured over time, such as the experience of students as they progress through courses (only course evaluations are undertaken), or the inconsistencies between the formal and informal curriculum. What lies beneath are the program structures: the way that the courses are formed together into a program. At the base of the iceberg is the underlying engineering education philosophy, on which the assumptions, beliefs and values around the program are based.

This aligns with the idea from systems thinking of increasingly effective leverage points (Meadows, 1997). In the case of the new program, we set about creating a new structure that challenges the assumption that a program consists purely of separate, individual courses. Features of this structure (shown in Figure 2) include:

- Five core courses, one in each semester of 2nd and 3rd year, and one that spans both semesters of final year (the dark blue boxes), each with defined learning outcomes, content to be covered and skills to be developed;
- Application streams that sit outside courses and provide a persistent focus for project topics within individual core courses, including opportunities that cut across the degree program from 2nd to 4th year (the light blue column);
- Projects of varying complexity, requiring groups of varying size and duration (the yellow boxes);
- An online Engineering Learning Commons containing content visible to all students throughout their degree (the pink outer columns);
- Topic modules that can be accessed just-in-time in self-study mode, and support flipped classroom pedagogies (the maroon boxes);
- Optional industry-based certificate frameworks linked to application streams (the green boxes).

Application streams capture complex interdisciplinary challenges and opportunities that the engineering profession is engaged with. Proposed streams include agri-technology, space engineering, sustainable cities, integrated transport, humanitarian engineering, and distributed energy networks. These provide a theme and contextual setting for projects in individual 2nd to 4th year courses. Students undertake projects from the start of second year with the opportunity to stay in an application stream conducting successive projects to deepen their expertise in the domain.

Application steams will be proposed from multiple areas, such as research groups, centres or initiatives, particularly those which are cross-disciplinary or cross university organisational structures. Many universities are increasingly supporting such themes and research, and this provides an ideal opportunity for research-led education and engaging students in big picture thinking of university research. Another source of application streams is external organisations such as companies, R&D labs or centres, the for-purpose sector, or government departments. In these cases, an external partner would commit to a longer engagement, but also a deeper one which may involve multiple staff. Other application streams could be proposed by students and linked directly to student competitions such as Formula SAE or the Australian Universities Rocket Competition (AURC), or broader challenges such as the World Solar Challenge. These provide opportunities for co-curricular learning and build from the support for such initiatives that universities already provide. For student teams, this provides opportunities for more structured team-handovers, development and planning.

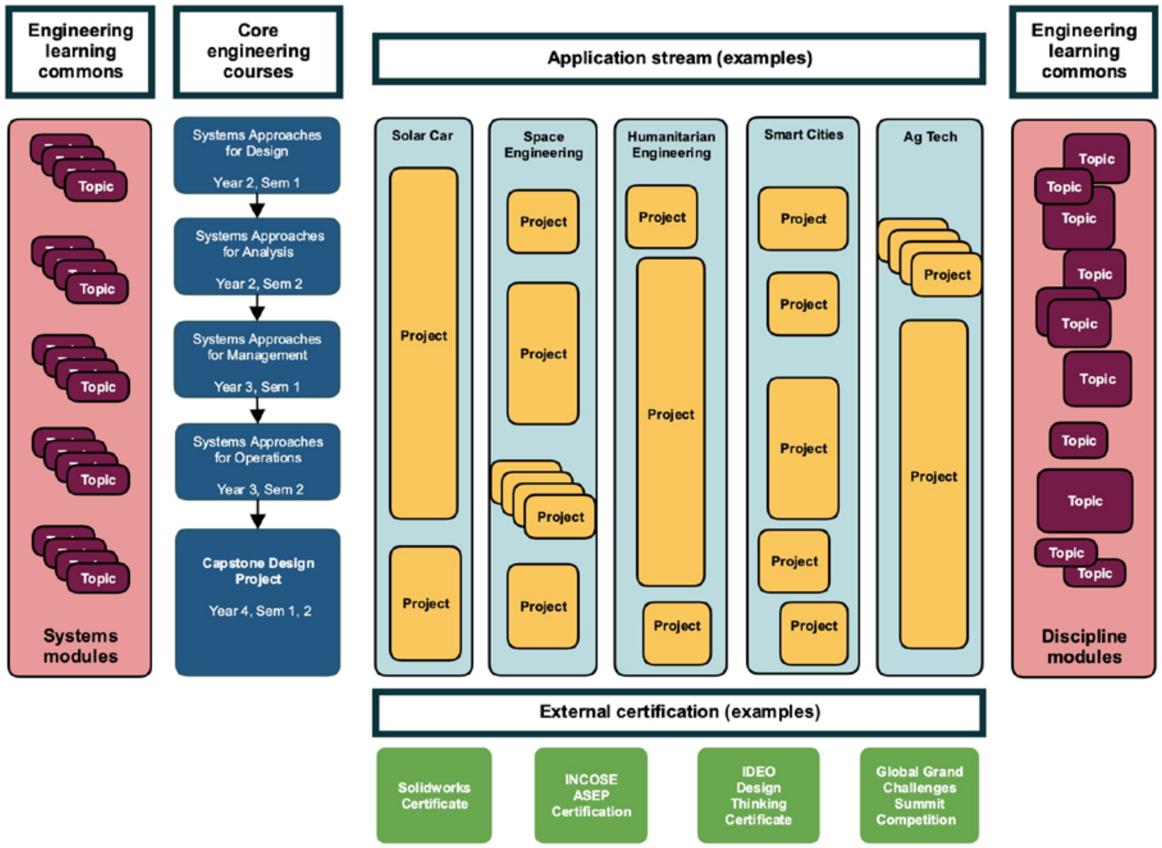

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Figure 2: Sequence of Core subjects alongside persistent application streams, with content modules drawn from the Engineering Learning Commons and external certification that can result from pursuing projects within the application streams.

Examples of industry-based certificate frameworks include the US National Academy of Engineering (NAE) Grand Challenge Scholars Program (GCSP). This provides a certificate framework of five elements, or competencies, of a contemporary engineer, being research, multidisciplinary, impact (entrepreneurship), multicultural and social connectedness. If a student demonstrates an appropriate level of engagement with these five elements for one or more of the NAE 14 Grand Challenges, they are issued with a certificate from the NAE recognising them as a NAE Grand Challenge Scholar. Where application streams align with the 14 challenges, such as smart cities, this gives an opportunity for students to be recognised for extending their learning through additional modules, extra-curricular activities, or external engagement. Other frameworks that are available include CAD certification for design-heavy streams such as the World Solar Challenge, INCOSE (International Council of Systems Engineering) Associate Systems Engineering Professional (ASEP) for space or defence-related streams, or IDEO's Design Thinking Certificates for product development or humanitarian engineering streams.

Like all systems, the interactions between the components are essential to the integrity of the design of the new engineering core:

- Much of the time and attention in core courses will be focused on projects, and much of the learning will be organised around the requirements of the project.
- Systems design and systems engineering modules in the Engineering Learning Commons correspond to core engineering content and are accessed by all students in the course in flipped-mode classes towards the start of semester;
- Students access disciple modules in the Engineering Learning Commons in self-study mode in the latter half of the semester in parallel with pursing their projects;

- Students may choose between a range of discipline modules for technical topics as appropriate to their application stream, for example statistics for electrical engineering or materials engineering;
- Industry-based certificate frameworks linked to application streams students to map individual learning pathways weaving together core course material, self-study modules, project work and extra-curricular activities.

The new design has many features that support the established goals of increasing engagement and interactions, increasing program stability and enabling opportunities for tailorable depth. These are outlined in Table 1.

Table 1: Design considerations and corresponding features of the new design.

Consideration	Design Feature
Related to Engagement and Interaction	
Enable student and staff collaboration across disciplines	Application stream projects encourage multidisciplinary perspectives, with students and staff working together in teams on projects.
Enable opportunities for peer learning	Applications streams open to students from years 2 to 4 to work closely on projects, with later year students naturally taking on a mentoring role to students at earlier stages of their degree.
Enable greater collaboration with internal groups and external organisations	Application streams are sponsored by internal groups or external organisations, who then act as mentors and coaches to students in the stream.
Enable formation of professional identity	Repeated opportunities to extend team and project-based activities develops a professional repertoire and portfolio of work.
Enable certification opportunities in support of professional identity	Articulation of learning to industry-based certification frameworks for students to a recognised association in addition to their engineering degree.
Facilitate an increase in student engagement	Application streams enable students to apply their learning to areas of personal interest.
Attract greater student diversity	Programs with a focus on application of engineering disciplines (rather than the discipline themselves) have above average female participation (Smith, Turner, & Compston, 2019).
Related to Program Stability	
Enable transparency of core content	Locating content in the Engineering Learning Commons enables all staff and students to see details of what is taught across all courses.
Enable structures resilient to staff changes	Greater transparency narrows the variation possible when teaching staff allocations change.
Enable scalability	The number of application streams can scale with changes to the number students, with streams added and removed in line with demand with minimal overhead.
Enable curriculum adaptability	Content can evolve as needed within the program structure;

	application streams can be added and changed much on much faster cycles as the interest of stakeholders changes without the need to invoke institutional assurance processes.
Enable ‘interest’ experiments	Interest for new majors, minors and programs can be trialled through application streams.
Related to Tailorable Depth	
Enable learning through doing	Topics studied are applied to projects as they are learned, enabling students to engage deeply with the subject matter in their studies and projects.
Enable engineering specialisation	Students can deepen their expertise through choosing an application stream closely aligned to their discipline, or establish a novel cross-disciplinary specialisation through their combination of discipline major and application stream.
Enable support for project work that requires a longer timescale	Projects can extend beyond a single semester – students may commence a project in one semester and articulate their learning on the project into the core course they are currently enrolled in, then continue the project in later course. Assessment will focus on how their learning in the project aligns to the learning outcomes of the current course.
Enable students to tailor their interests	When selecting projects, students can choose to engage with topics in a given application stream of interest, or move across them to gain breadth experience.
Enable discipline-specific content to support learning in the core courses	A wide range of discipline-appropriate self-study modules can be provided in the Engineering Learning Commons and accessed by students to meet the needs of their project. Students can access additional modules if required for discipline courses outside of the core.

The new design requires approaches to staffing and resourcing that align with the components, rather than simply assigning five conveners to separately teach the five courses according to the course specifications. This is not an increase in staff time and responsibilities, but a reallocation. While increasing the diversity of staff roles, the burden of each of the teaching roles is reduced in this design. Course conveners will no longer be responsible for sourcing and resourcing multiple projects opportunities for students in their course. Each application stream will be led by a Champion, responsible for linking with industry sponsors and mentors, coordinating the scoping of projects, and supporting students to succeed in their projects. Course conveners will also have reduced responsibility for delivering content, as much content will be accessed directly by students form the Engineering Learning Commons. The role of the course convener will be in facilitating students to engage with the relevant systems and discipline modules, encouraging them to apply the content learned therein to their project, and assessing student attainment of the learning outcomes for the course, changing the role of the course convener to mentor rather than instructor.

Conclusion

As highlighted in numerous reports, shifting the public perception of engineering is critical for its future practice, in terms of recruitment and community understanding (Crosthwaite, 2019).

Application streams will become the primary lens through which students experience the engineering core. This puts the focus on the domains where engineering disciplines are used rather than the disciplines themselves. The new design includes many features that are expected to increase engagement and interactions, increase program stability and enable opportunities for tailorable depth.

Operationalisation of the new engineering core is in progress. Students having enrolled in a Bachelor of Engineering (Honours) from 2019 will follow this new curriculum, with the new second year courses commencing in 2020. Details relating to curriculum, governance and operations required for the success of the program have been identified. During the period of paper deadlines for this conference, the project-enabling support for this curriculum change are being established.

Implementing the new design well requires establishing all of the components and the interactions between them, which in turn requires a thorough understanding of the systemic structure of the new design. Unlike previous interventions at the course level, the new program design challenges the very structure of the program. The iceberg model of education programs reveals the underlying structures as a powerful leverage point that could lead to systemic transformation. However this change to established academic practice may not change the underlying engineering education philosophy—the base layer of the iceberg—within the school. Changing culture is challenging, and it is still ongoing for the case study here, with the final outcome yet to determined.

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