Work in Progress: A Case Study on Large-Course First-Year Engineering Design Projects

Abstract

This work-in-progress paper outlines an approach to project-based learning (PBL) in a first-year engineering design course for all students in the school of engineering at a large research university. Compared to the previous version of the course, emphasis is placed on working through uncertainty in the design process, making the course more appealing to indigenous and New Zealand students, and more directly connecting topics to second-year discipline-specific design classes. The course presents a generic design process from problem understanding through to testing and documentation. Two design-build projects, one individual and one team-based, allow multiple "trips" through the process, with chances to reflect on and discuss the presented design process. Process content is supported by skills development in spatial visualisation, CAD and technical drawing, and basic analysis techniques.

Background of staffing, space allocation, material costs, and students are described to provide context; the course aims and methods are described; student feedback is summarized; and plans for evaluation and further development are outlined.

Introduction

In their review of project-based learning (PBL) in engineering education literature, Chen *et. al.* highlight the challenge of increased time and effort required by students and teachers to tackle the "messiness" of open-ended design problems.[1] Particularly in large first-year courses, implementing and assessing these open-ended design problems is difficult due to resource (space, staffing, time, financial, etc.) constraints. Finding an appropriate balance between concrete and open-ended design projects is critical to maximizing students' learning.

ENGGEN 115: Principles of Engineering Design is a required first-year course in the Faculty of Engineering at the University of Auckland. The course was re-designed in 2022 to emphasize design process over technical engineering, promote creative problem solving, and to test a concrete/open-ended balance that might work for the combination of curriculum, student cohort, and faculty arrangement in the authors' institution. In particular, compared to the previous version of the course, the number of design-build projects in the course was doubled from one to two and their open-endedness significantly increased.

Course Background

Context

ENGGEN 115 is required for first-year engineering students and is therefore taken before students declare a major within engineering. Course management is split between the Department of Civil Engineering (including the Structural Engineering major) and the Department of Mechanical and Mechatronics Engineering, so conscious effort is made to provide design examples from across the different engineering disciplines offered within the faculty.

While the new version of the course did not change in format (as outlined in **Table *1*** below), the previous version of the course was delivered in four distinct sections: conceptual design, 3D spatial visualization, CAD and technical drawing, and the design project (popsicle stick trusses).

This format allowed easy distribution of teaching load among the instructors across the semester but did not fit the broader curricular vision for engineering design. The course redesign was undertaken to align with this vision and emphasize hands-on projects as the best vehicle for first-year engineering design process education, yet still fit within the prior institutional constraints (e.g., size, time, exams, etc.) of the course.

Table 1: ENGGEN 115 described in numbers.

Property	Description
Course year	First year – before students select a major within engineering
Semesters	2 per year (Autumn and Spring)
Students	~500 per semester
Credits/Points	15 (15 student hrs/wk expected, including face-time and homework)
Lectures	2 x 1-hr per week (nominal)
Tutorials	1 x 2-hr per week (max 35 students per tutorial)
Semester	12 weeks + 1 x 2-week mid-semester break
Exam	Required by the university to be worth 50% of the course grade

Course statistics

Table ***1*** above and **Table** ***2*** below each outline relevant statistics about the course and how they are run within the Faculty of Engineering. These are meant to allow the reader to easily compare the course as described to similar courses at their institution. Note that the list of costs does not include things like computer labs or other resources used by multiple courses within the Faculty of Engineering or the university.

Table 2: Course cost outline. Staff are represented in portion of Full Time Equivalent (FTE) or total semester hours, space is represented in square meters and hours per week, and materials in USD.

Quantity	Description	Cost
3	Lecturers (academic staff)	~0.2 FTE each
1	Course Coordinator (academic staff)	~0.2 FTE each
1	Teaching Technician (professional staff)	~0.1 FTE
8	Lead Tutors (postgraduate teaching assistants)	160 hrs per semester
4	Support Tutors (undergraduate teaching assistants)	50 hrs per semester
6	Markers (postgraduate students)	100 hrs per semester
1	Lecture hall for 550 students	1 hr per week
3	Tutorial rooms for 35 students	12 hrs per week
520	DP1 material kits for individual students	USD 6.00 per student
100	DP2 material kits for student teams	USD 4.00 per student

Course Description

Goals in course development

When designing the new ENGGEN 115, the original Teaching and Learning Outcomes remained unchanged:

1. Develop skills in engineering sketching, drawing, and graphical representation (Washington Accord attribute WA1)
2. Develop understanding of the engineering design process (Washington Accord attributes WA1, WA2, WA3, WA5, WA9, and WA10)
3. Develop professional engineering work practices and principles (Washington Accord attributes WA6, WA7, and WA8)

The new course, however, added supplemental goals to address particular challenges identified in past versions of the course:

- Helping new university students adapt to the open-ended nature of design problems: Seow et. al. highlight the need for universities to produce students who can thrive in a volatile, uncertain, complex, and ambiguous (VUCA) work environment.[2] Instructors at the University of Auckland have repeatedly noted first-year engineering students' discomfort with uncertainty in their design courses as they transition from high school into university. Nolte and McComb found that design students experienced more stress in physical modelling and concept generation than in concept selection. [3] By increasing the emphasis in the course on concept generation and physical modelling (i.e., by adding a design-build project and requiring more concepts before concept selection), instructors hope to show students the benefits of remaining longer in the uncertain phases of the design process to generate more and better concepts.

- Making the course and the topic more appealing and welcoming to indigenous students and New Zealand students in general: Tying the design process to be taught, design projects, and lecture case studies to topics relevant to indigenous and New Zealand students is intended to attract and maintain students' interest in the large and diverse class.

- More directly connecting what students learn in the first-year design course with their discipline-specific design courses in years 2, 3, and 4: Drawing examples from second-year design courses will serve to help students make a more informed choice of engineering specialization at the end of their first year. In addition, the authors expect the examples to help students more directly apply what they learn in ENGGEN 115 to their discipline-specific courses in later years.

Structure

The structure of ENGGEN 115: Principles of Engineering Design are shown in **Figure *1***. The focus of the course is on design process (about 1/3 of the lecture content), which is supported by the course's primary vehicles for learning: the three design projects (DP1, DP2, and CAD DP).

These projects are, in turn, supported by trainings (via lectures and supplemental clinics) in three skills of an engineering designer: spatial visualization, CAD, and engineering analysis.

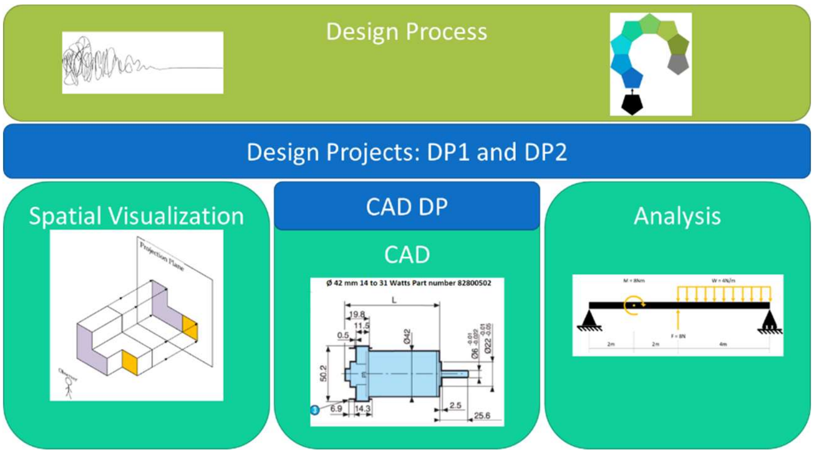


Figure 1: Course structure shows the Design Projects as the primary learning vehicle for the course, supported by conversation around Design Process and a set of useful skills for engineering projects.

The design process used by the course, illustrated in **Figure *2***, was developed to be generic enough to apply to any engineering discipline. It consists of three design phases, each with their own output document.

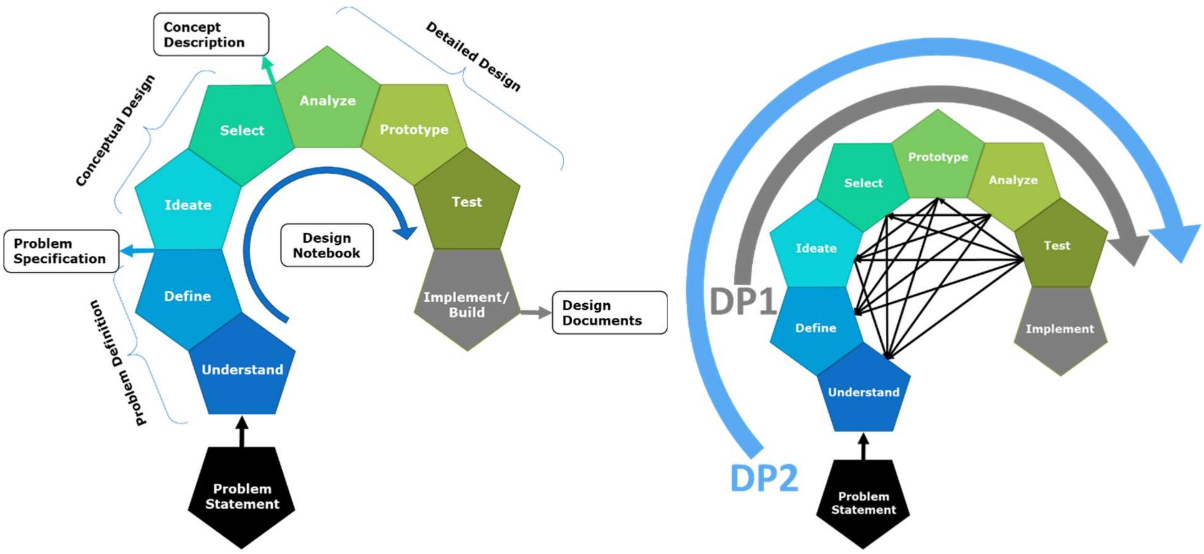
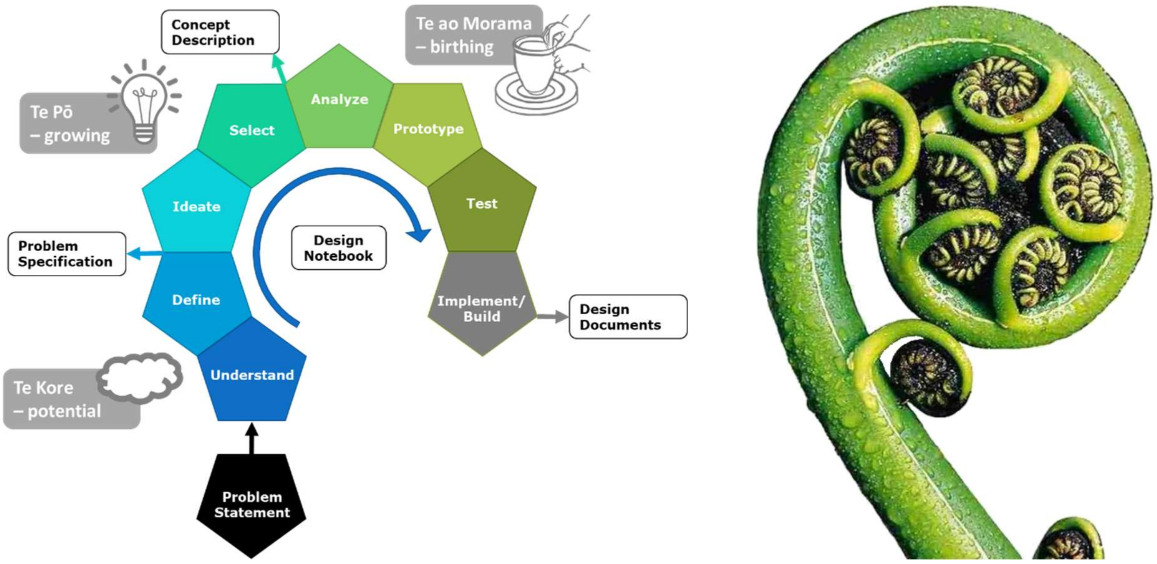


Figure 2: The ENGGEN 115 Design Process is generic enough to apply to any engineering discipline (a). The messy and iterative nature of design is illustrated through additional arrows, and the scopes of the two design projects identified in (b).

- The **Problem Definition** phase encourages background research, stakeholder assessments, and deep understanding of the problem beyond the original problem statement. This phase concludes with a Problem Specification document which captures the relevant technical, social, organizational, and cultural constraints for the given problem.
- The **Conceptual Design** phase focuses on brainstorming and then down-selection of concepts utilizing criteria from the Problem Specification document, and produces a Concept Description document outlining the selected concept.
- The **Detailed Design** phase utilizes the engineering tools required to make informed design decisions and leads to a build product which is ready for implementation in some form.

The ENGGEN 115 Design Process, shown in **Figure *3***, was developed in collaboration with Māori colleagues to incorporate words in te reo Māori, the native language of Aotearoa New Zealand. In addition, the very common Māori image of the koru inspired the shape of the design process diagram. This is particularly fitting, as the shape of the young fern plant illustrates the iterative nature of the design process. Just as the design process can be applied at the micro-decision-making scale and the grand project scale, the koru shows small spirals embedded within the larger curl of the main stem.



(a) (b)

Figure 3: To connect the ENGGEN 115 Design Process to New Zealand and Maori culture, te Reo Maori names have been provided for each of the phases (a) and the diagram is in the shape of the 'koru' from Maori imagery.

Projects

The design projects in ENGGEN 115: Principles of Engineering Design are intended to guide students through the design process three times during the semester in slightly different configurations.

DP1: The Animal Rescue Tower

DP1 is an individual project in which each student must design, build, and test a small tower from cardboard to support a given amount of weight via the Ideate, Select, Analyze, Prototype, and Test steps in the ENGGEN 115 Design Process. The first two steps of the process, Understand and Define, are left out of DP1 to help students get started quickly and keep them from being overwhelmed by a large, vague, unusual task right at the start of the course. The project brief includes a completed Problem Specification document, allowing students to start the project with the ideation step.

DP2: Museum Movers Exhibit

The second design project of the semester expands the experience relative to DP1, tasking students to start "earlier" in the process with the Understand and Define steps and produce their own Problem Specification document. After generating their own concepts, students are placed in teams of 4 to 5 to follow the remainder of the design process.

CAD Project

The CAD project is a final opportunity for students to step through the design process, this time in a digital format without the same feedback of a physical design-build project. 3D Spatial Visualization, CAD, and technical drawing skills are used to conceive and visualize a physical situation like a museum exhibit.

1.1 STORY

Animals are trapped down several abandoned mine shafts. As part of the rescue effort you, as an engineering designer, have been asked to design a tower for raising a particular animal up from a particular mine. A number of these towers need to be built and they vary (depending on the mass and dimensions of the animal and the size of the opening to the mine) but you are being asked to design and build a tower for *only one* scenario (animal + mine shaft).

Figure 4: The DP1 brief outlines a story to prompt students to build a tower from cardboard, wooden skewers, and popsicle sticks (but no adhesives).

Materials

The design-build project in the prior version of ENGGEN 115 was a truss-building exercise using popsicle sticks with metal nut-and-bolt joints. This project design limits design decisions to member lengths and thicknesses (number of popsicle sticks) and their arrangement in a truss form, effectively emphasizing truss analysis to achieve an optimal design. In the redesign of the course cardboard is used as the primary building material because of its simple form and flexibility to take on different shapes. Working with malleable sheet material opens up the design space to allow more creativity and, in so doing, generates greater uncertainty in what the final design will look like.

Design Notebooks
Students must maintain a design notebook throughout the projects, documenting their progress through the design process.

1.1 STORY

The local science and engineering museum has signed up to participate with other museums in creating and displaying a set of exhibits which get cycled between the museums over the next two years. Each museum will create one exhibit, then they will be rotated among the different museums on a regular basis. The exhibits all travel in the same package: a 3m x 3m x 3m crate. Rather than simply move the crates into and out of the museum at night, your local museum's management has decided to take this opportunity to turn the moving of the crates itself into an engineering exhibit for museum visitors.

Your engineering design firm has been asked to propose a design for a "**Movers Exhibit**" that demonstrates one or more engineering concepts while moving the crates from the delivery platform up to the door to the museum.

Figure 5: The DP2 brief presents a scenario in which teams of students must design a mechanism to move a large crate up a ramp. Teams of 5 students will then build scale models of their chosen designs out of cardboard and other materials (including adhesives).

Presentations
Both DP1 and DP2 include in-class presentations of students' final design models.

Evaluation
As a Work in Progress, evaluation of the new course is still underway. Measuring the learning impact of course redesigns is challenging; Saterbak et. al. note that the neutral result in their study of student performance before and after the introduction of a flipped model is consistent with much of the similar work in the literature.[4] For this course, two specific aspects will be targeted for evaluation, corresponding to particular student competencies the authors hope to improve.

Student creativity and comfort with uncertainty
As described above, the redesign of ENGGEN 115 attempts to strike a new (for the course) balance between concrete and open-ended design problems in PBL. Yang found that sketch volume generated in the first quarter of the design cycle correlates significantly with design outcome.[5] To assess students' willingness to sit in uncertainty at the beginning of a design project, a study is planned focused on the number of initial concepts a student or student team generates before moving on to concept selection and prototyping.

Teaching staff surveys

Because performance in ENGGEN 115 helps determine the rank order in which students are allowed to choose their engineering specialization, there is pressure from students and the faculty to keep the course consistent between semesters in a given year. For this reason, course improvements are only implemented at the start of the academic year and the first cohort of students to take the new version of ENGGEN 115 is only now enrolled in their second-year discipline-specific design courses. Surveys of teaching staff (both lecturers and technicians) in those courses will seek to compare students from the old version of ENGGEN 115 to the students who have completed the new version. Surveys will look to uncover differences in students' comfort with uncertainty and the carry-over of terminology and techniques from the first-year course into subsequent design courses.

Discussion and future work

Course evaluations in the first year of the revamped ENGGEN 115 showed improvement over previous years, but also offered plenty of room for improvement. In addition to the evaluation work above, current plans include tying the tutorial activities more directly to projects and lecture content, drawing more case studies of good and bad engineering design from industry practitioners, integrating CAD and an analysis task into DP1, and improving written assessment rubrics to promote more consistent marking across the course and semesters.

References

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