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Design at Scale in a First-Year Transdisciplinary Engineering Design Course*

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Many Canadian engineering faculties employ a first-year design course. Offering a large-scale, realistic and valuable design experience to students beginning to learn about engineering is challenging. In 2020 the Faculty of Engineering (University of Alberta) introduced a new first-year design course for 1200+ qualifying year students: Introduction to Engineering Design, Communication, and Profession. The course is founded on four principles: engineering design is a distinguishing and core feature of engineering practice and education, transdisciplinary engineering design has a common process, sustainability is a key societal goal and integral to engineering design, and the communication of the evaluated design proposition is a necessary step towards design implementation. The course objectives are to introduce first-year students to the transdisciplinary design process and demonstrate differences between the engineering and traditional science programs. The course design had four additional requirements: (1) meet the needs of all our programs; (2) be taught by instructors from each of our disciplines (supporting transdisciplinarity and discipline ownership); (3) engage applied learning; (4) use the design process to solve a community-based problem. The course implementation was supported by two co-lead instructors, the continued involvement of a third design instructor (course co-creator), eight guest instructors (representing all Faculty programs and the provincial professional association), and ten teaching assistants from both engineering and industrial design programs. All course materials (lecture slides, online resources, project descriptions, assessments) were developed in advance. Even as we were implementing this new course, we were collecting midterm feedback, reflecting on and adjusting the course in real-time, and planning the next iteration using a continual improvement process. At the time of original submission, the aim of this paper was to provide insight into the course development, implementation and lessons learned through its delivery. However, with the COVID-19 pandemic, many more challenges faced the instructional team; these are also detailed in this paper.

Keywords: large classes; first-year; design course; first-year engineering; transdisciplinary; implementation; course continual improvement

1. Introduction

Design is the integrative component of engineering education crossing both engineering disciplines and design disciplines knitting us together in transdisciplinary teams. As a graduate attribute, design is defined, in the Canadian engineering accreditation context, as "An ability to design solutions for complex, open-ended engineering problems and to design systems, components or processes that meet specified needs with appropriate attention to health and safety risks, applicable standards, and economic, environmental, cultural and societal considerations" [1]. Furthermore, Engineers Canada is recommending that "Engineering design should ideally be a culminating aspect of program integration and should demonstrate connections amongst the technical skills and knowledge presented in programs. As such, appropriate design education weaves through programs as a connecting thread. Design should occur in every academic year at a level commensurate with the abilities of the learner" [2].

Engineering schools across Canada undertake teaching design differently; for example, some use a design spine approach with required design courses taken every year, some have design content permeating engineering science courses throughout the program, while some integrate engineering fundamentals and contextual learning near the end of the program as part of capstone courses, and some use a combination of these approaches. A growing number of Canadian engineering schools now have a first-year program that explicitly includes design. A challenge of teaching design in the first year can be the scale required to offer a realistic and useful design experience to a large number (1200+ at the University of Alberta) of students who are just beginning to learn about engineering science and disciplines.

While the stages of design can be defined in several ways, all involve some combination of problem scoping, developing and evaluating alternative solutions, project realization, validating and reporting with sketching and prototyping [2–6].

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Comparisons of experts and novices show that expert designers spend more time at all stages of the design process, with the largest difference being at the problem definition and information gathering stages [7]. Indeed, many studies have shown the importance of problem scoping to the design process [3, 8, 9]. Additionally, experts not only gather more information, but also more diverse information about the problem, and they consider more objects during the design process compared to students [3]. These are all skills which students would benefit from instruction explicitly designed to teach to them.

In addition, the types of design problems addressed in a first-year course can vary from a product prototyping experience to a community-based project. The choice of problem type can be influenced by the number of students, the resources available, program diversity, and whether or not an introduction to complexity and sustainability is a desired component of the course.

2. Background

At the University of Alberta, engineering programs have a common qualifying first year followed by discipline selection prior to the second year. Before 2020, most programs taught design later in the program, some with design included in engineering science courses, and one program utilized the design spine approach. Typically, each program was responsible for deciding where and when design was taught within their curriculum. In 2015, a faculty-wide meeting of design instructors across our programs indicated a desire for an earlier design experience for students, preferably in the common first year. A transdisciplinary group of design instructors, representing the four departments in our faculty, namely, Civil and Environmental Engineering, Chemical and Materials Engineering, Electrical Engineering and Mechanical Engineering, developed an educational framework for undergraduate engineering design and the basis for the learning outcomes for this new course [10]. This was followed by an in-depth research project to develop the learning outcomes with an emphasis on transdisciplinarity and design [11].

In 2017, the development of a new first-year design course, Introduction to Engineering Design, Communication, and Profession, began and implementation was targeted for the 2020 winter term. The primary aims of this course were to introduce first-year students to a transdisciplinary design process and demonstrate the difference between engineering and traditional science programs. The six stages of the transdisciplinary design process developed and used in the first-year course are: Planning (PL), Concept Development (CD), System Level Design (SLD), Detailed Design (DD), Implementation and Testing (IT), and Production (PR). Learning outcomes were grouped in three major themes: the design process itself; communication including teamwork, technical drawing, technical writing, and presenting; and introduction to the profession including professionalism, health and safety, ethics, and project management. We defined transdisciplinarity as "the application of theories, concepts, or methods across disciplines with the intent of developing an overarching synthesis" [12]. In our case, the course content itself was transdisciplinary as were the instructional teams.

2.1 Importance of Transdisciplinarity

Transdisciplinary collaboration is a complex form of project-focused collaboration between disciplines on real-world complex problems, such as sustainability [13]. According to Gibbons et al. [14], these design problems require input from multiple disciplines with a shared theoretical understanding and agreed-upon interpretation of knowledge. Transdisciplinary design requires individuals with competencies in two or more disciplines. As a result of this fluency, a transdisciplinary perspective emerges [15]. As engineering collaboration is complex and involves many types of collaboration, Stein's disciplinary framework [15] as outlined in [16] is used to define disciplinary interactions. In this framework, collaboration progresses from disciplinary to multidisciplinary to cross-disciplinary to interdisciplinary and finally to transdisciplinary on the basis of the developmental progression of *individual* collaborators beyond their initial discipline expertise from understanding another discipline to emerging competence to primary and secondary competencies to the transdisciplinary fluency competence in two or more disciplines.

In 1972, at the first international conference for interdisciplinary studies, Erich Jantsch outlined a framework for collaboration amongst disciplines. He defined the need for transdisciplinary collaboration when set problems became too complex for any single discipline to tackle on their own and that multiple disciplines are required sharing knowledge, theories and practices. He also noted the collaboration is project-focused and often is centred on real-world problems [16, 17]. Transdisciplinary design requires knowledge, concepts, or methods from at least two disciplines, without a predominant discipline [15], applied in a broader context beyond any of the individual disciplines [16]. Transdisciplinary design embodies a new and/or unified perspective used to explore complex problems that span multiple disciplines.

There has been growing recognition within higher education of the need to create purposeful transdisciplinary learning opportunities for students [18] to cultivate a transdisciplinary perspective and lay the foundation for individual lifelong learning and collaboration with multiple disciplines. Societal goals have been shifting towards global sustainability, diversity, inclusivity, and equity. Social responsibility aspects of professional practice have been developing in parallel with the growing recognition of the complex nature of engineering problems [19] that requires individuals with transdisciplinary collaborative capabilities. Engineering education presents a specific challenge when we recognize the range of engineering disciplines within the profession in addition to the increasing disciplinary span within engineering responsibility including engineering leadership and management.

While there has been consistent and growing development of transdisciplinary practices within research communities, innovation hubs and in large complex industrial projects, often academia has been slower to respond [20]. It is imperative that engineering education further embraces opportunities to incorporate transdisciplinary learning opportunities throughout the curriculum.

We identify three key benefits – and there are others – resulting from integrating transdisciplinary learning opportunities within engineering undergraduate education.

Transdisciplinary learning environments better represent professional working environments. Engineers collaborate in teams comprising a wide range of disciplines. Working in teams that span disciplines has unique challenges – different histories, languages, and practices – and embedding these learning opportunities within undergraduate education ensures students gain productive experience in a structured and positive pedagogical format [21].

The scope, challenge and complexity of engineering projects are growing. Increasingly, problems being addressed are transdisciplinary in nature. These challenges – termed wicked problems by Rittel – are often ill-formulated, confusing, and involve many participants with conflicting values [22]. Wicked problems require the involvement of decision-makers that span disciplines. Working successfully on these complex challenges involves collaborating with a variety of professions and developing skills and perspectives beyond one discipline. The opportunity to develop these skills within an undergraduate engineering education is crucial.

The depth and breadth of engineering continues to expand. As specializations within engineering become more specific, disciplines develop their own methods, practices and ways of working. There is a need for students to be able to learn how to effectively work and communicate across and within these specializations. The early development of transdisciplinary insight may help engineers to maintain connections across the profession and encourage the development of individual transdisciplinary competence.

3. Transdisciplinary Course Design: Objectives and Goals

3.1 ENGG 160 Course Design Principles, Requirement, Constraints, and Implementation

A key goal during the development of the first-year design course was to present a core transdisciplinary design process aligned with design as it is practiced and taught in the different engineering programs in our Faculty. To achieve this goal there were a number of principles and requirements constraining and shaping the course design and content. The key principles are:

- engineering design is a core feature of engineering practice and education;
- complex and real-world problems often require a transdisciplinary perspective;
- transdisciplinary engineering design has a common process;
- sustainability is a key societal goal and integral to engineering design; and,
- communication of the evaluated design proposition is a necessary step.

The first requirement was the course must meet the needs of all our programs by developing design, team, leadership, project management, contextual, and professional skills relevant to all engineering graduates. An extensive project was undertaken to develop a transdisciplinary framework for course design and implementation to achieve this goal [10]. This initial development work is represented on the left-hand side of Fig. 1. The further development of team, leadership and professional skills in a sustainable design context was identified during our continual improvement process. Redesign elements are represented in the bottom right of Fig. 1.

The second requirement was the content must be taught by instructors representing each of our program disciplines to ensure a sufficiently broad perspective on design is presented to students. This aspect is represented by the guest instructors in Fig. 1 and the selection of teaching assistants from across our core disciplines (Fig. 1 top right). We wanted students to appreciate that there is a core design process with a variety of viewpoints and characteristics applied in discipline-specific design. Additionally, it is crucial to ensure all programs are well represented to minimize course delivery-based bias that could potentially impact student discipline selection for their second year. The faculty includes such diverse programs as civil and environmental engineering, chemical engineering, computer engineering, electrical engineering, engineering physics, material engineering, mechanical engineering, mining engineering and petroleum engineering.

The third requirement was applied learning – the design project undertaken must require the application of design and professional skills and be something first-year students could realistically accomplish. Our project development criteria were: it can be completed by a team of students within the allotted time frame [23] and it does not require advanced engineering knowledge or modelling. The design project aspect was implemented in the first iteration by the lead course instructors and the teaching assistants while the rotating guest instructors delivered the core material from a discipline perspective. The material the guest instructors delivered was developed by the course designers and the guest instructors were allowed to make small modifications.

Finally, a focus on using the design process to solve a community-based problem was required. This aspect was central to our desire to demonstrate how engineers solve problems that contribute to society. It is also central to demonstrating the transdisciplinary nature of the design process and the need to consider multiple perspectives and stakeholders. Project examples included: the design or redesign of an urban park, the design or redesign of a recreation center, the redesign of an intersection, a mini campus, a school playground, a transit center, and a seniors' recreation center. All project descriptions included client requirements and user requirements, which were intended to help develop transdisciplinary insight and awareness of diverse sources of information required as design inputs including the technical requirements, regulations constraining their design solution options, and the stakeholder requirements.

There were also several constraints which the new course had to meet. The schedule constraints required this course to be taught as a blended course with one synchronous face-to-face lecture and two asynchronous online lecture equivalents per week early course designers identified and worked within these constraints (Fig. 1 bottom left) and these constraints continue to impact redesign options and decisions (Fig. 1 bottom right). The final constraint was our capacity to assess students' communication skills. While developing written and oral communication skills are course objectives, the participation of over 1200 students makes it impractical, ineffective and costly to organize in-person oral presentations or to review lengthy final design reports. To balance time and resource constraints with aligned course assessment, the major team-based deliverables are: a short written project proposal focused on developing plausible solutions and a design evaluation and decision matrix; and a 2–3 minute final report video presenting the final solution overview and expected challenges. Further, the mandatory English course, ENGL 199, is a co-requisite of ENGG 160. In the course, students are taught many of the communications skills critical to ENGG 160 and their programs, namely, writing a proposal, creating proper images and presentations, and presenting their work to their peers and instructors.

3.2 Blended Learning Course Implementation

All materials for the blended course, including lecture slides, online resources, and project descriptions were developed in advance of the first implementation of the course. In its first iteration, the course was supported by two co-lead instructors (biomedical and mechanical engineering and design), the continued involvement of a third design instructor who is a co-creator of the course (chemical engineering and design), eight guest instructors representing all Faculty departments

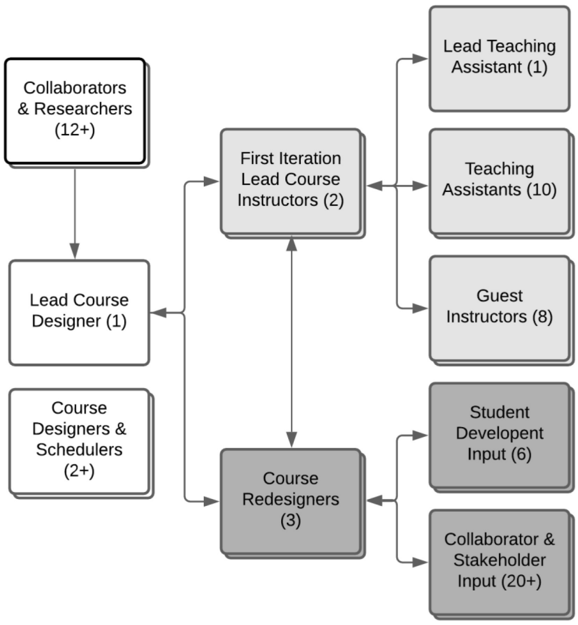

Fig. 1. Course collaborator, designer, instructor and teaching assistant relationships through course research and development process (white), first-time implementation (light grey) and continual improvement course redesign (darker grey). The bidirectional arrows represent the bidirectional communication between design, implementation and redesign in the design, implementation and continual improvement phases. The single direction arrow represents the one-way research data gathering process used to define the transdisciplinary design process used to initially develop course content. Numbers with a + indicate minor involvement/review input from a larger group of people.

and programs, one guest lecturer from the provincial professional association, and ten teaching assistants (TA) from both engineering and industrial design programs, one being the lead TA. The core teaching team included the lead TA who provided ongoing support and mentorship for the TA team during the course. The TA role was to mentor students as they applied the design process taught in class to their projects. By meeting with the students periodically and coaching students on team dynamics and project requirements, the teaching assistants were an essential component of the instructional team.

Table 1 describes the face-to-face (F2F) lecture topics and program instructors, the associated online learning activities, and the course assessments. Guest instructors are listed by discipline. Each of the four departments that offer our nine programs are represented by the guest instructors. The blended learning course included online learning components that were both independent of and related to the F2F components of the course. An important consideration was that the online learning could not take more than two hours per week as stated in the course calendar listing (1-0-2): comprising one hour of F2F activities and two hours of online activities. Course designers were cognizant of the first-year workload and it was of utmost importance to consider student mental health.

The lectures were initially created by the course development team. The presentation templates were provided with prescribed content; the guest instructors were asked to add their discipline perspective to the content and deliver the material as they saw fit in the classroom. The aim of this

Table 1. ENGG 160 schedule of activities

Wk	Face to Face	Online	Assessment
1	Course Introduction Project Explanation *Lead Instructor*	Introduction to Profession	Quiz 1 Self-Evaluation
2	Introduction to Engineering Design: Process, Methodologies, Stages, Iterations, Product Life-Cycle *Lead Instructor*	Teamwork & Communication Programs & Design Videos	Quiz 2
3	Planning: Problem Definition, Customer Needs, Requirements, Objectives, Constraints *Mining Instructor*	Design Project Management Project Management Tools	Quiz 3
4	Concept Generation: Generating Ideas, Brainstorming, Divergent Thinking, Creativity, Innovation, Design Recycling, Conceptual Design, Multi-Use Design Tools *Chemical and Materials Instructor*	Liability, Risk, DFX, Safety, Standards, Codes, Regulations, Research Tools	Quiz 4 Team Evaluation
5	Decision-Making, Idea Evaluation, Decision Matrix, Product Functionality, Feasibility *Mechanical Instructor*	Engineering Ethics	Quiz 5
6	System-Level & Detailed Design, Design in Different Disciplines, Components, Sub-Systems, Systems, Specifications, Form vs Function, Reviews *Petroleum Instructor*	Sustainability, Environmental Stewardship	Quiz 6 Proposal Due
7	Graphical & Technical Communication in Different Disciplines, CAD Tools *Mechanical Instructor*	Visual Communication	Quiz 7 Team Evaluation
8	Implementation & Testing: Prototyping, Product Safety, Iterations, Production & Manufacturing: Materials, Cost, Quality *Electrical Instructor*	Workplace Safety & AOHSA	Quiz 8 EHS Training
9	Real-Life Industrial Practice, Transdisciplinarity & Business in Engineering (Discussion) *Chemical and Materials Instructor*	Life-Long Learning	Quiz 9
10	Guest Lecture – Design Professor Solving Problems in Real-time *Industrial Guest Speaker*	Graduate Attribute Survey	Quiz 10 Design & Programs
11	Choosing Disciplines: Admission Factor, Perks of Co-op, Choosing Minor (or Business in Engineering) 2 First-Year Nights *Associate Dean*	Program Selection	Program Selection
12	Guest Lecture – Equity and Diversity *Mechanical/Environmental Instructor*	Online Work Wrap-up	Team Evaluation
13	Guest Lecture – APEGA *Guest Speaker*	Online Work Wrap-up	Video Report GA Survey

approach was to ensure the required content was delivered, to maintain content consistency year over year, and to reduce preparation time for guest instructors.

Online learning components not listed in Table 1 include:

- Specific readings from the mandatory textbook [24] and additional suggested readings from another textbook [25];
- Videos developed in-house on our various programs presenting discipline perspectives on design and its role in these fields;
- Videos developed in-house of guest speakers relating their experiences using the design process in practice at their place of work; and,
- Topical video resources found on the internet.

Course assessments include:

- Short quizzes on each topic to ensure that learning outcomes were met;
- Self and team evaluations were completed through ITP metrics to assess team dynamics;
- Safety training pertinent to program activities and the profession;
- Graduate attribute self-assessment survey;
- Program selection activities to choose their program discipline; and,
- Project deliverables, a written project proposal and a video final report.

Students were initially randomly assigned to teams with 8 members. Working group size varied from 6–10 students due to team reorganizations and students withdrawing from the course. Team size was larger than the typical capstone design team size of 5–6 members [26]. This was done for a number of reasons. The first was to focus on a rotating set of responsibilities between members and for students to experience the complexities of larger team dynamics. The second was to ensure that there was sufficient experience and interest in different activities being proposed in the course. We wished to ensure that each team had a broad base of diversity, opinions, and backgrounds. Workload sharing was also an important consideration. Finally, the course had limited resources to support over 200 teams of 5 members.

Continual improvement is a core tenet of the Canadian Engineering Accreditation Board accreditation process and for our Faculty of Engineering. Even as we were implementing this new first-year engineering design course, our instructors and teaching assistants were collecting midterm feedback, reflecting on and adjusting the course in real-time, and considering what would work better in the next iteration.

4. Methods

A continual improvement methodology including instructor and TA observations, assessment results [27], and post-course reflection [28] was used to identify possible course design, assessment, and delivery improvements. This methodology, detailed in prior work [27, 28], requires gathering stakeholder input in various formats and identifying the key improvement areas. This included the collection of anecdotal thoughts and comments from students for course improvement and the collection of reflections and ideas for learning activity improvements from the ten teaching assistants and our guest instructors. Teaching assistant ideas were captured both formally – at mid and end-of-term review sessions – and informally throughout the term by the lead teaching assistant. In addition, a year-end review session with the teaching team including the co-lead instructors and teaching assistants helped to inform these reflections. The objective was to maximize benefit and course improvement for the least amount of redesign effort between course iterations. More formal midterm student feedback was collected by the lead instructor and was immediately integrated into the initial course delivery where possible. The focus of the following sections is the post-course reflections and resulting changes to the course.

A post-course continual improvement meeting was conducted after the course by one of the co-instructors for the purpose of collecting and assessing improvement strategies from contributing guest instructors. The co-instructors met with all the TAs both during and after the course to discuss course delivery, student assessment, student engagement, logistical difficulties students had with teamwork, issues encountered and their impact alongside anecdotal feedback from students as to the strategic choices they made during their second term of their first year. A composite summary of the observations and reflections is presented in the next section followed by the improvements identified for the Winter 2021 iteration of ENGG 160. This aspect is represented in the bottom right of Fig. 1 and is the basis of the data collection for the course redesign for Winter 2021. This process was complicated by the COVID-19 pandemic as was the course redesign, forcing innovation and further consideration of course materials and delivery methods.

5. Observations and Reflections

All new courses have their ups and downs, bumps and challenges, and ENGG 160 was no different. It is however important to note the significant impact of COVID-19 and accompanying public health measures had on the delivery and conclusion of the course. On Friday, March 13, 2020, the University of Alberta suspended all classes and activities until remote delivery classes resumed on Tuesday, March 17, 2020. On March 20, 2020, the university moved to a credit/no credit (CR/NC) grading system for all courses. It should be noted that the latter did not affect ENGG 160 which was already CR/NC. On the same day, students in residence were asked to leave unless they were unable to; most undergraduate students left, while graduate students remained in residences. On March 23, 2020, the university implemented stringent reduced campus access to students in addition to cancelling our Universal Student Ratings of Instruction (USRI) feedback system for all Winter 2020 courses. It was a stressful transition time for all and student access to University resources and community sites was limited.

As with all universities nationally and worldwide, the closure of the university and most of the residences led to many international students and many with permanent residences outside of the university region returning home before the end of the term. In our first-year cohort, and therefore in ENGG 160, 29% of the students were international. In many of these cases, students returning home faced quarantine restrictions, had internet connection or technology issues, or may not have had any internet access. The university has a Google-based email and drive/software system that students use for their work; in some countries, these platforms are banned. Google Meet, a virtual meeting app widely used for team meetings was unavailable to many. Fortunately, eClass (our university learning management system) was not affected by such restrictions allowing for class delivery and assessments to continue with the addition of the Zoom meeting application.

Students see time as their most precious resource as they work to achieve grades for a competitive discipline selection process during a demanding second semester; when midterm weeks approached, prior to and after reading week, class attendance began to drop. Studying and preparing for core first-year mathematics, physics and chemistry courses can be time-consuming. Anecdotally, these courses were seen as a priority compared to a credit course with no impact on their GPA and discipline selection standing. The week before the university went online because of COVID-19, many students and/or their parents had already decided that there were too many risks associated with a course section of 350–400 students and two of the three sections had no attendance. Therefore, the final half of the course was very different from the first and few students valued in-person attendance for a course where all readings and presentations were available online for asynchronous review. Students did attend the online lectures when instructors were able to host a live session and they did attend sessions with their TAs via Zoom after the switch to online delivery.

5.1 Teaching Assistant Reflections

The role of the teaching assistants was to bridge communication between the instructional team and the students, to be design mentors for their student teams, and to assess deliverables according to rubrics. Each teaching assistant was responsible for 15 groups of approximately eight students. The lead teaching assistant managed the teaching assistants to ensure consistency in different aspects of the course including assessment evaluation. Although design concepts remain ubiquitous, teaching assistants were able to tailor their advice to the students and share their individual experiences based on their backgrounds. Teaching assistants did indicate that better-defined roles and responsibilities towards their teams would have helped; however, overall, they reported their experience with the first-year design course as positive.

The first iteration of the course was successful, though not without its challenges. A major challenge faced by the teaching assistants in managing the course learning activities was the size of the design teams. We observed that teams of eight students were too large for a first-year engineering design course and the project workload. Teams often complained of the lack of contribution of one or more members and how it was often difficult to convince inactive team members to contribute. This observation was further confirmed by the fact that several design projects were completed without the contribution of all members of the design teams. Attempts to reach out to these unresponsive students by the teaching assistants were often unsuccessful.

In addition to the lack of contribution of some members, communication between the team members themselves was also brought up as a challenge. Coordinating the schedules of eight first-year engineering students was nearly impossible for some teams, even with block course registrations. Some students were unable to meet with the teaching assistants during the entire semester and some did not connect with their team at all. Assigning roles in these larger design groups often meant some students were paired in performing similar parts of the project. For future iterations of the course, many of these challenges could be overcome by assigning fewer students to design groups, by using synchronous time for design teamwork and TA and Instructor meetings, and better facilitating informal course communication. Adding more details to the group project assessment rubrics, which would help identify specific tasks, could also eliminate role redundancy.

Based on this first implementation experience, we note that it is critical to provide TAs with a clearer framework for the TA role, expectations of students, and course requirements to help execute their tasks. Better TA preparation in advance of the course and helping them to develop as a supportive team were identified as areas for improvement in the next iteration of the course. For the first iteration of the course, however, teaching assistants were successful in managing up to 15 groups and felt they could manage more groups with fewer students with similar course expectations and grading workload. Smaller groups would reduce the probability of team conflicts and role redundancy, allowing the teaching assistants to spend their time coaching and mentoring design students rather than settling team disputes and attempting to connect with non-participating students.

5.2 Course Delivery, Content Reflections and Resulting Improvements

The next phase of course redesign and development held many challenges. There were several lessons learned from our observations and experiences with both the pre- and mid-COVID-19 course delivery methods. The instructional team did not expect to be teaching face-to-face (F2F) until 2022. Both instructors and TAs noted variable engagement during the course, they noted student teams struggled to find time to connect and find the time for key learning activities. There were issues with limited participation for some students, and sometimes confusion with the content, especially team and project management.

The first lesson was lecture content and learning activities needed to focus more on the design project team activities to maintain student engagement, better guide student learning, and build a community of practice. Future lectures will be shorter and provided asynchronously online prior to returning to F2F and likely after a return to F2F. Keeping content online and focused allows for synchronous class time to be spent on in-class team activities related to progressing the design project. This flipped and blended strategy allows for the instructors and TAs to more actively engage with and mentor teams as they are more available to address team questions and concerns during class time. This can be achieved in either a F2F or online format. Both formats have advantages and disadvantages for student-to-student and for student-to-instructor interactions. Communication amongst the students was complicated in the first iteration of the course by the effects of the COVID-19 shutdown of the traditional classroom and many students returning home. This aspect had to be addressed in the remote delivery version of the course.

The second lesson was balancing the value of the individual course activities with the required overall grade to receive credit for the course. We observed many students following the minimum path to obtain credit rather than focusing on learning and achieving the course objectives. In planning for the next iteration, we shifted more weight to the project deliverables and increased the requirements for participation in activities to obtain credit. We increased the criteria for a pass from an overall accumulation of 65 points to an activity mastery threshold with all activities to be completed in a gamified format. We also created weekly formative project progress assignments leading up to the major design team assignments. These staged assignments are graded as complete/not complete based on effort. Formative feedback is given to assist students in developing their work towards the successful completion of the major assignments. By incorporating an effort-based assessment approach we hope to increase active participation in learning, obtain better engagement with the design project application, develop team and professional skills, achieve greater team integration and reduce contribution inequity. Incorporating aspects of gamification [29] into the course structure and marking was considered and then implemented in the next course iteration.

The third lesson learned is to reduce the group sizes to 5 or 6 members. In an effort to create broad and diverse teams, other complications arose, such as the amount of work to be done and complex team dynamics. The TA team found a lower number of larger teams did not equate to less work or hours spent on mentoring and guiding teams. A smaller team size of six students was in place for the next iteration of the course.

Fourth we learned that first-year students had limited conceptions of what their roles might look like in a design project, what the milestones of the project might be and how to translate this into what each person is responsible for and when it should be due. The large group size exacerbated these issues as students assigned tasks and roles to two individuals to ensure everyone had work to do. We determined more in-person support was required for this aspect and should be provided during the synchronous classroom activities and the online learning activities. We also decided to rework some of the early course material to have students consider a team charter and the possible roles team members could take on in the context of a predetermined project schedule. This decision led to an increase in the number of TAs required to run the course as more formative feedback to smaller teams meant more people were required to deliver this level of interaction with the student teams.

Fifth, we needed to better align the course content and design projects with sustainable development as the overarching motivational factor for transdisciplinary design processes and personal development. Although our projects were community-based, this overarching aspect was not as strong as we would like it to be and the student desire to learn more about sustainable design was clear from their comments to us during the first iteration. Sustainability and sustainable development principles needed to be strengthened in the course to provide a better foundation for sustainability in the discipline programs. In addition, some of the individual and team development activities moved to the first term ENGG 100 course: Success in Engineering to make room for this aspect. The course objectives in ENGG 100 includes developing small student communities that carry through to ENGG 160 in the second term of the the first year. Topics that will be included in this move are engineering leadership, personal, and team development. We must be mindful of the overall workload students have in the second term of first year. We planned to reduce the workload in ENGG 160 by further developing professional skills and fostering a better understanding of what it means to be an engineer in our first term course. This realignment of course components allowed for greater focus on the transdisciplinary nature of ENGG 160 while building upon broader skills introduced in ENGG 100. While student teams were able to complete project requirements in the first iteration, these adjustments better suited the shift towards better role definition and schedule development while balancing the weekly formative project requirements and workloads proposed for the second iteration. We proposed to allow teams formed in ENGG 100 to continue in ENGG 160 if they so choose. The realignment of some course components allowed for greater focus on cross-disciplinary interactions and the transdisciplinary nature of design, professionalism, team development, and project management early in the course.

Finally, we elected to include a hands-on design component as a learning activity in order to give students experience with the implementation and testing of a design idea and allow them to explore the later stages of the design process. This presents organizational and budgetary challenges for materials should prototyping be included. The resources required for 200 teams to use our makerspace would be well beyond its capacity. However, by focusing on a sustainable hands-on challenge using recycled materials available at home, the psychomotor skills, creativity and critical evaluation learning outcomes can be further realized. A simple hands-on exercise early on in the course can also serve as a team-building and bonding exercise. Using materials destined for recycling allows us to entertain this challenge for both F2F and remote delivery modes.

6. Limitations

Our purpose was to provide the reader with the details, successes and challenges experienced during the development and delivery of a large transdisciplinary first-year design course. The review of the course outcomes followed a well-established continual improvement assessment process. The key limitation of this study was the ability to undertake course review and assessment as a result of the COVID-19 pandemic. The findings presented were confounded by the late-term change in delivery mode and the resulting lack of direct interaction with students and the instructional team. That noted, anecdotal evidence, student and instructional team feedback led to identifying clear goals for the winter 2021 course delivery.

7. Conclusions

Overall, the first iteration was observed to be a generally positive experience for students, TAs, and instructors. Key improvements and changes to better support student learning were identified as part of the continual improvement process and the redesign work for the second iteration began with remote delivery as a new constraint. We learned that our limited synchronous in-class time, whether face-to-face or online, should be spent being actively engaging with student teams as they are working on their projects and that the project work required more deliberate and staged guidance on a weekly basis. These items would address some of the observed engagement and teamwork issues we faced in the latter half of the first iteration of the course. We were successful in managing the progress of the design teams and the assessment of the project proposal and the video report within our constraints and we were able to build on this to develop a strategy for the remote delivery of the second iteration of the course. It was an incredible team effort, involving instructors and teaching assistants, to deliver at scale both pre and mid-pandemic. That said, the instructional team recognized the need to continually improve the course and will focus future efforts on team dynamics and size, use of asynchronous content, deeper integration of course activities with sustainability concepts, greater in-class time for project-related activities, and incorporating a do-it-at-home hands-on project. In implementing a similar course, particularly very large courses, instructors should consider not only the course changes we suggest but also the implementation of feedback collection processes from all stakeholders to support evidence-based, continual improvement in their own teaching and learning contexts.

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