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Paper ID #36359

Redesigning an Introduction to Engineering Course as an Interdisciplinary Project-Based Course

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Full Paper: Redesigning an Introduction to Engineering Course as an Interdisciplinary Project-Based Course

Abstract:
All first-year engineering students at Bucknell University are introduced to Engineering through a first-semester, required course taught by faculty members representing six departments and eight degree programs. In 2021, this cornerstone course was re-envisioned with modern and emerging pedagogical approaches and greater consistency across course sections. While the engineering design process was the central content, the redesign integrated concepts and activities to address teamwork, written and oral communication, information literacy, engineering ethics, local and global sustainability, and inclusion. This paper describes the redesign process and the intentions behind the redesign itself, the common theme of sustainability integrated through all projects, and the scaffolding structure that was established across all sections. The challenges and opportunities that arose in the first iteration of the redesign course are highlighted along with the next phase of continuous improvement.

Introduction and Purpose

Many universities require a first-year cornerstone course for incoming engineering students, and Bucknell University is no exception. The college-wide introductory course has been delivered in a seminar-based format to approximately 200 students each year since its last revision in the 2002-2003 academic year [1], nearly 20 years ago. While the previous version was successful [2], opportunities for improvement became apparent in recent years. A redesign of the course was undertaken in 2020 and first implemented in Fall 2021. The purpose of this paper is to document the process of the redesign and to share the "lessons learned" from the pilot offering of the newly revised course.

Background Information

Bucknell University is a predominantly undergraduate institution with a College of Engineering located within the liberal arts context. The College of Engineering enrolls approximately 200 students each year, currently divided among eight degree programs (Biomedical, Chemical, Civil, Computer, Computer Science, Electrical, Environmental, and Mechanical Engineering). ENGR 100 is the introductory course required for all incoming first-year engineering students and open to students in Arts and Sciences or Management. This course is one of four courses in the common, first semester curriculum for all engineering students.

The previous version of ENGR 100, titled *Exploring Engineering*, offered a general introduction to engineering as a profession followed by discipline-specific 3-week seminars that were selected by the students to explore various disciplines within engineering. The course concluded with a segment on professional ethics and a team project. The seminar-based format was advantageous from a faculty perspective because of the autonomy available in each seminar to focus on a topic of their choice using pedagogical approaches they deemed most appropriate. The seminar-based format gave students the opportunity to explore various disciplines and experience different instructors/styles. While this achieved the learning goals of the course, several challenges and concerns arose to prompt the redesign. Seminars were typically content-driven but did not emphasize a common set of skills across seminars or cultivate the design-centered passion and

curiosity of a new student. In addition, a single coordinator was responsible for managing the logistics of the course and this time-consuming effort did not allow much time for progressive thinking.

To approach the redesign, three faculty members from three different departments in the college proposed a team-based coordination to model the teamwork and interdisciplinarity necessary in engineering practice. The coordination team hosted focus groups over the spring/summer of 2020 engaging: a) students who had previously completed ENGR 100, b) faculty who had previously taught in the seminar-based format of ENGR 100, c) faculty who had not previously taught in ENGR 100, and d) previous course coordinators, some of who were involved in the previous redesign from 2002. The coordination team also met with the College of Engineering's leadership. These meetings and focus groups enabled the coordination team to collect feedback about the strengths and areas for improvement within the ENGR 100 course and more general desires for the first-year engineering experience. Through these meetings and focus groups, common desired attributes of the redesigned ENGR 100 course included: design-focus, hands-on projects, transferable "power" skills, transferable "technical" skills, and engineering ethics. In addition, the coordination team was also encouraged to consider how the redesign course could impact the college culture and first-year experience. Aspirationally, the course could 1) fully reflect Bucknell's engineering identity nested in the liberal arts, 2) generate excitement for the engineering profession and the remainder of the engineering education at Bucknell, 3) build community and inclusive behavior, and 4) emphasize professionalism.

To place this Bucknell-specific information into context, the coordination team also explored the literature on the various pedagogical approaches utilized for first-year engineering courses and other high-impact practices. Because first-year engineering courses vary widely from institution to institution, it was important to understand the context and goals associated with these practices. The various first-year engineering courses were grouped according to their focus and the advantages and disadvantages of each group were evaluated relative to the desired outcomes of the redesigned ENGR 100 course at Bucknell. The primary groups included: 1) courses that focused on the introduction of specific skills (i.e. CAD, fabrication, programming), 2) courses that focused on design (design process and design thinking) [3], and 3) project-based courses [4]. The team did not explore discipline-specific introductory courses.

The desired attributes for the redesigned course were mapped to the various pedagogical approaches from the literature, and it was determined that a project/design-based approach would provide the best opportunity for achieving the desired attributes and aspirational goals for the course. When using the term "project-based", we acknowledge that it is actually a hybrid of problem/project-based as described by Prince and Felder [5] where the students are acquiring new knowledge in the pursuit of designing a solution to an open-ended problem.

Redesign process

The desired attributes and aspirational goals for the course informed the creation of new course outcomes that would ultimately focus and prioritize course-level efforts appropriately. The associated ABET student outcomes are identified in parentheses. *Course Outcome #1 - Develop creative solutions for problems facing our world by applying engineering design principles, math and science, and data analysis (ABET 1, 6).* Proficiency in problem solving using the engineering design process is the priority of the course. Aspects of engineering design such as

the application of mathematics and science to answer hypothesis-driven design questions, collecting and analyzing data, and using specific design-centered techniques (ideation, background research, etc.) are introduced in the context of a team project. *Course Outcome #2 - Construct an effective prototype or model utilizing appropriate technology and tools (ABET 3, 6).* Active prototyping is a requirement for the course, with an emphasis on low-fidelity approaches. We recognize that "prototyping" or modeling is different across various engineering disciplines, and thus implementation of specific tools or hands-on approaches is not explicitly prescribed. *Course Outcome #3 - Demonstrate improved proficiency with "power skills" such as communication, teamwork, information literacy, and professional development (ABET 3, 5).* Course coordinators chose the language "power skills" to describe complementary skills that are often described as "soft skills", as this term places a greater perceived value on abilities such as communication and teamwork. These skills are associated with professional leadership success and are typically not associated with traditional engineering curricula [6]. *Course Outcome #4 - Employ the NSPE code of ethics to examine ethical case studies and extrapolate principles for other situations (ABET 4).* Engineering ethics is crucial to any engineering program. By introducing engineering ethics in the first semester, we aim to develop a foundation for further coursework and generate student outcome data that can be used for curricula development or ABET assessment. In this course, engineering ethics is covered by first introducing a specific method with which to approach difficult ethical dilemmas - the Vesilind process developed by Aarne Vesilind [7] - followed by repeated case study applications.

The Engineering Design Process (EDP) - the main focus of this course and outcome #1 - is a general approach to solving design problems by leveraging engineering fundamentals. While the EDP does not have a single accepted definition, it follows an iterative process loosely defined by problem identification, ideation, and prototyping/construction. For the purpose of an introductory engineering course, we defined the EDP as having five steps and three "essential ingredients" (Figure 1). While other EDP definitions may include more detail or specific language such as "prototype" and "test", we chose to balance specificity with applicability across a range of possible design projects and scenarios.

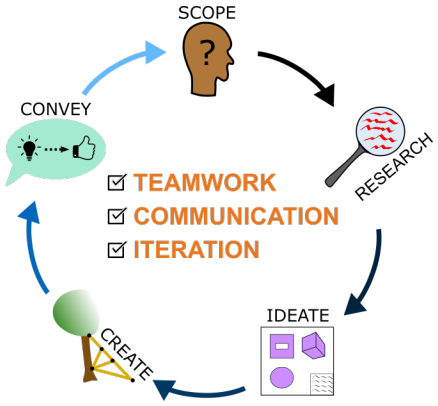

Figure 1. The Engineering Design Process (EDP) graphic used.

Early in the redesign process, the coordination team decided that a single course theme would provide a common set of language and learning opportunities for course-level activities, assignments, and initiatives. After considering a range of themes (community engineering, global sustainability, accessibility engineering), the theme of Sustainability on Campus was selected. In addition to the highly relevant topic of sustainability, we chose to focus on campus sustainability to provide students with an authentic engagement opportunity "close to home". We defined sustainability as "meeting our own needs without compromising the ability of future generations to meet their own needs", acknowledging the three pillars of sustainability - environmental, social, and economic. Each course project was centered around solving a problem related to sustainability on campus. While different degree programs interact with sustainability in various forms, sustainability presents a clear opportunity for interdisciplinary projects.

The course was structured around two major design projects, each tackled in a "Design Session" (Figure 2) where faculty were responsible for overseeing and supporting student groups working on a design project. Class time emphasized hands-on project-based activities in teams rather than purely technical content. A schedule of each Design Session (DS) was outlined by the course coordinators and faculty were provided with storyboards for each day. These storyboards included key talking points, suggested activities, and important visuals for class time, but stopped short of a completed slide deck or detailed program for the day, enabling individual faculty to bring their own pedagogical approaches to the course. Design Session projects included addressing food waste on campus, developing sustainability-focused apps, and the development of sensors for a smart building. Commonality in scope and assessment across Design Sessions and projects was achieved through three common Benchmark assignments. Each Benchmark included specific goals for the project along with an assessment rubric.

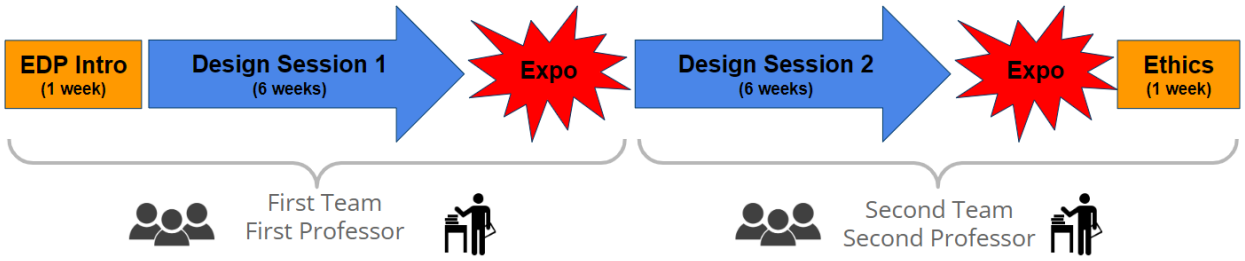

Figure 2. General course timeline.

Design Session 1 emphasized learning the Engineering Design Process (EDP) in detail, including data collection and analysis and low-fidelity prototyping. In Design Session 2, students were expected to be able to complete certain EDP steps (such as researching the larger problem) with less instruction, enabling more of an emphasis on advancing data collection, analysis, and prototyping. The specific power skills emphasized in each DS also varied, with the first half of the course and Expo 1 emphasizing visual and written communication, with the second half and Expo 2 emphasizing oral communication. Each Expo included additional professional development opportunities for students such as free headshots provided by a professional photographer and were open to the campus community. The culminating Expo at the end of each DS provided each team an opportunity to present and demonstrate their project to a wider audience as shown in Figure 3. Ethics week followed a similar format to prior years, and was not an area of emphasis for the Fall 2021 redesign.

a) DS1 Expo (formal poster presentation and low-fidelity prototype)

b) DS2 Expo (flash talks and higher-fidelity prototype)

Figure 3. ENGR 100 Expos.

Lessons Learned from Fall 2021 Pilot

The new division of the semester-long course into two equal time frames and in turn creating two design sessions of 5 and half weeks each had numerous benefits. However, from a student perspective, the other three weeks of the semester spent on the introduction of the EDP, ethics, and other non-design project work were not as engaging. Therefore, we would like to further simplify the course schedule to have just two longer design sessions and integrate the non-design project work more effectively in the second iteration of the course.

ENGR 100 successfully became one of the few classes offered in Bucknell College of Engineering where the faculty or student discipline/department/major was not the focus of lessons or discussions. Rather, the course emphasized one single identity as an engineer, and students undertook the same assignments, deliverables, and goals regardless of declared major. The course provided a uniform opportunity for students to equitably thrive in the comfort of the first-year engineering community. For the faculty, the uniformity and normalization of course materials ensured that the faculty members spoke to students using the same engineering language, and the project-based format allowed the faculty to actively engage with and teach the students without prioritizing individual disciplinary obligations.

Student course evaluations highlighted “hands-on” and “open-ended” nature as reasons for deep student ownership in the DS projects, which translates to the high level of engagement in the course. In particular, the official, professional Expo venues were critical for all the students to gather simultaneously and showcase their work and practice their communication skills. The natural deadline of Expos required student teams to follow a schedule and reach a high level of project completion, and the Expo floor provided a place for the students to receive validation on their accomplishment in their first semester as an engineer. The interdisciplinarity of the course helped in providing a consistent, positive atmosphere during the Expos.

Many student course evaluations criticized the lack of coverage of disciplinary introductions and individual major information in ENGR 100, partly because the former versions of the course had done so for over 20 years. These comments are in direct conflict with the intention of the redesigned interdisciplinary format of the course to de-emphasizes disciplinary information in class. We plan to work with relevant campus partners to address this misunderstanding and discuss with the co-instructors to overcome this tension.

Many first-semester students are not prepared for a project-based college course and courses that emphasize teamwork responsibilities. Because these are both major components of the redesigned course, social awareness and ability to conduct two-way conversations with instructor and team members are crucial. Some students suffer from lower course and project engagement scores due to a lack of understanding of these expectations - both implicit and explicit. This observation calls for a more robust scaffolding and support for teamwork, as well as a redefinition of what it means for course and project engagement opportunities to be equitable for students with different personalities and from different backgrounds.

Ethics is one of the core learning goals, and the pilot year followed the previous format of providing the ethics portion of the course as an isolated, one-week topic at the end of the

semester. The course evaluation results pointed to some students appreciating a change of pace from the back-to-back design sessions. However, we believe that engineering ethics is a fundamental topic that should weave through and integrate with the Design Sessions to teach its application in a real-world setting.

Next Steps

With the first iteration of the redesign course complete, the planning for the second iteration is underway. Under consideration is the opportunity to integrate the engineering ethics session into the design sessions in an authentic manner so it does not appear to be separate from or an afterthought to the engineering design process. Improved scaffolding and support for students adapting to the project-based and teamwork-intensive nature of the course will be a focus for the second iteration.

With the initial focus and investment on the curricular design of the course, it is essential that the coordination team consider a long-term plan for sustaining and continually improving this course. Factors to consider include: transitions for coordination team, future course themes and complementary campus partners, ongoing data collection (pre- and post- student surveys, faculty input, etc.), and a regular assessment period.

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