The Development and Evaluation of a Series of New First-Year Engineering Courses

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Abstract— The current Research-to-Practice, Work-in-Progress paper presents the development, launch, and preliminary evaluation of a series of four new introductory engineering courses at Princeton University School of Engineering and Applied Science (SEAS). The courses were designed to address the findings of a university-wide strategic planning process that revealed students' dissatisfaction with the first-year engineering experience and a higher attrition rate of students from groups traditionally underrepresented in engineering. Early findings from an in-depth, mixed-methods evaluation reveal that the courses are succeeding in increasing students' satisfaction with the first-year engineering experience and reducing the attrition rate of students from underrepresented groups.

Keywords—first-year engineering; project-based; evidenced-based teaching; engineering self-efficacy; and retention

I. Introduction

The current *Research-to-Practice, Work-in-Progress* paper presents the development, launch, and preliminary evaluation of a series of four new introductory engineering courses at Princeton University School of Engineering and Applied Science (SEAS). The courses were developed after completion of a university-wide strategic planning process that resulted in the recommendation to transform the first-year engineering experience. The self-study conducted during the strategic planning process revealed that students and alumni were most unsatisfied with their freshman year experience due to a lack of exposure to the various engineering disciplines and few opportunities to cultivate relationships with engineering faculty. Furthermore, the self-study revealed that the greatest number of students exiting the engineering program at the end of the first-year were students from groups traditionally underrepresented in engineering. Specifically, while overall attrition from SEAS is 30%, it approaches 50% for African American students, 40% for Hispanic students, and is over 40% for women.

To address the attrition rate and lack of satisfaction, a team of engineering faculty and colleagues with expertise in engineering education and student development collaborated to design and implement a series of four introductory courses to satisfy the SEAS freshman math and science requirements and to serve communities with minimal prior engineering experience. Two courses focus on synthesizing science and engineering and two courses focus on synthesizing math and engineering. The two science-engineering courses are *Foundations in Engineering: Mechanics, Energy, and Waves* and *Foundations in Engineering: Electricity and Photonics* (heretofore EGR 151 and EGR 153, respectively). The two math-engineering courses are *Foundations in Engineering: The Mathematics of Shape and Motion* and *Foundations in Engineering: Linear Systems* (heretofore EGR 152 and EGR 154, respectively). The purpose of this *research-to-practice, work-in-progress* paper is to summarize the literature that informed the development of the courses, describe the courses, present the evaluation plan and preliminary findings, and identify next steps.

II. Literature Review

During and after the strategic planning process, we reviewed literature on student-active pedagogy, first-year engineering experiences, and engineering retention and student satisfaction. Extensive research indicates that utilizing student-active pedagogy, improving faculty-student interaction, and enhancing students' engineering self-efficacy contribute to an increase in cognitive gains, student satisfaction and persistence, e.g. [1] - [5]. The most effective approaches require that students become actively engaged in the process and receive frequent feedback while learning [6] - [9]. Engaging students during class provides an opportunity for written and oral reflection, peer-to-peer instruction, student-to-faculty interaction, metacognitive analysis, and continuous formative feedback.

Various techniques and strategies for employing student-active pedagogy include, but are not limited to: problem-based learning, technology-enabled student response systems, journaling, case studies, and flipped classrooms. Utilizing these techniques result in positive gains in student cognition and affect [10] – [13]. Utilizing these techniques in project-based, introductory engineering courses have been shown to be effective in increasing retention and student satisfaction [14]. These studies reveal that utilizing evidence-based, student-active pedagogy increases students' STEM content knowledge and affect for all students, but is especially beneficial to students from underrepresented groups.

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Guided by the literature, we utilized a theoretical and analytical framework that guided the development of the courses and the evaluation plan. The faculty developed courses (described in section III) that outlined specific curricular goals, aligned assessments with course goals, utilized student-active pedagogy, provided opportunities for enhanced interactions between students and engineering faculty, and taught science and math in the context of applied engineering problems. Our evaluation plan seeks to understand the impact of the courses on students' STEM content knowledge and engineering affect, as these constructs are linked to student success and satisfaction, eg. [1] and [4].

III. The New Courses

Prior to the development of the new courses, students had two pathways into engineering during their first year: (1) take two math courses, two physics courses, one chemistry course, one computing course, and one writing seminar; or (2) for students with advanced standing, take a project-based two-semester course that integrates calculus, physics, and computing, along with one chemistry course, and one writing seminar. The faculty transforming the first-year engineering experience sought to add an additional pathway that would enhance engineering faculty and student interaction, introduce students to the different engineering disciplines early in their academic careers, and address poor retention rates of students from underrepresented groups in the engineering school. The third pathway replaces the four traditional introductory physics and calculus courses with a series of four courses that are taught by engineering faculty, with equivalent content as the introductory physics and calculus courses but embedded in the context of engineering problem-solving and design.

The overarching goals of the courses are to enhance students' STEM content knowledge and affect, as well as to increase the retention of diverse students. After a thorough review of the sophomore-level engineering courses that serve as introductions to the various engineering disciplines, the faculty identified key science, math, and engineering content topics. Those topics informed the development of the four new courses, which are the units of analysis of this paper. The courses are:

- EGR 151 covers mechanics, energy, waves, and introductory thermodynamics within the framework of understanding and developing engineering solutions to grand global challenges; i.e. the focus is on the role an engineer plays in responding to grand challenges and the physics foundations that are at their disposal. The course includes a laboratory component, comprised of projects designed especially for the engineering-minded student, focusing on design and building, problem solving, and entrepreneurship.
- EGR 152 is an introductory course for single variable calculus. The material is presented in a manner that shows how calculus combined with analytic geometry is the language of expression for quantitative ideas in science, technology, engineering, and mathematics itself. The course covers differential and integral calculus, series and sequences, and Taylor series to discuss topics such as information and probability, the physics of planetary motion and statistical mechanics, and the development of computational algorithms.
- EGR 153 explores the fundamental principles of electricity, magnetism, and light. An underlying theme is how these fundamentals both underpin grand societal challenges as well as enable paths toward engineering solutions and innovation. Broadly speaking, the course focuses on the application of information technology, energy and power, bio-engineering and sensors. The labs enable students to explore basic principles as well as test their own designs based on those principles.
- EGR 154 covers the basics of algebra with linear systems, vectors, matrices, matrix multiplication, systems of equations, matrix inversion, diagonalization, eigenvalues and eigenvectors, determinants, and some basic probability/Markov chains. These topics are taught in the context of engineering problems that are centered around grand challenges facing society today, including information and security, bioengineering and health, structures and circuits, and machine learning.

IV. Evaluation Plan

The purpose of the evaluation plan is to understand the students' lived experiences in the new EGR courses. We are interested in evaluating the extent to which the courses impact students' cognition and affect. The research questions guiding the evaluation plan are:

1. *To what extent do the new sequence of courses enhance students' science, math, and engineering content knowledge?*
2. *How do the engineering courses impact students' affect (confidence, attitudes, motivation, and engineering self-efficacy)?*
3. *What are the salient features of the engineering courses that enhance faculty-student interaction?*
4. *How do students describe the Princeton University and SEAS community, climate, and culture?*

To answer the guiding questions, we are collecting and analyzing six primary sets of data: (1) longitudinal focus groups with students and faculty, (2) classroom observations of the courses, (3) course assessments, (4) pre- and post-surveys focused on cognition and affect, (5) student survey data from the Office of Institutional Research, and (6) students course enrollment data for their freshmen and sophomore years. Currently, we are comparing the September 2017 pre-survey and February 2018 post-survey data, and analyzing November 2017 and March 2018 focus group data.

The pre-survey was administered during the first two weeks of the fall semester to EGR 151 and EGR 152. Of the

46 total students in those courses, 33 students completed the pre-survey (72% response rate). The first post-survey was administered during the first two weeks of the Spring 2018 semester to EGR 153 and EGR 154. The purpose of the first post-survey was twofold: it (1) served as a post-survey to assess the impact of EGR 151 and 152, and (2) served as a pre-survey to collect baseline data from students who did not enroll in or take the pre-survey during EGR 151 and EGR 152. A total of 48 students enrolled in EGR 153 and/or EGR 154. Of those students, 29 students completed the post-survey (60% response rate). Of the 29 respondents, we matched 20 pre- and post-surveys. Of the 9 unmatched surveys, 3 students had not taken EGR 151 or EGR 152, enrolling for the in the new sequence of introductory courses. Twelve students participated in the focus groups conducted on November 17, 2018, and eleven students participated in the focus groups conducted on March 28, 2018. The IRB-approved consent process, surveys, and focus groups were administered by members of the research team who are not members of the teaching team.

To assess student affect, a survey was developed using the Students' Assessment of Learning Gains [15] and Longitudinal Assessment of Engineering Self-efficacy [16] surveys as guides. The SALG survey was developed to measure student assessment of their own learning. The LAESE was developed to measure self-efficacy changes over time for undergraduate engineering students. Both have been well established to provide valid and reliable data. A loosely-guided focus group protocol was informed by the survey questions. The questions on the pre-survey and the first post-survey attended to the first two research questions. The focus group data attended mainly to the third research question, but also provided information on course content. The following section summarizes preliminary findings.

V. Findings

The purpose of the evaluation plan is to understand the students' lived experiences in the new EGR courses. We are interested in evaluating the extent to which the courses impact students' cognition and affect. At this point, pre- and post-survey and focus group data provide some information to address the first three guiding research questions.

The survey consisted of 3 subscales: Attitude, Concepts, and Skills. The Attitude subscale measured students' enthusiasm for and interest in engineering, as well as confidence in their ability to complete certain tasks related to earning a degree in engineering. The Concepts subscale focused on students' assessment of their understanding of various engineering topics. The Skills subscale focused on students' beliefs in their ability to apply various engineering related concepts, as well as their comfort with interpersonal skills.

To establish reliability of the data used for this evaluation, Cronbach's alpha was computed for each subscale at both pre- and post-time points: The Attitude subscale consisted of 9 items (α_{pre} = .812, α_{post} = .912), the Concepts subscale also consisted of 9 items (α_{pre} = .923, α_{post} = .728), and the Skills subscale consisted of 14 items (α_{pre} = .944, α_{post} = .906). All subscales were found to provide reliable data. Once sufficient reliability was established, a pre-to-post analysis was conducted using paired samples t-tests. For each of the 3 subscales, there was a statistically significant increase in average score from pre-to-post. Fig. 1 shows the average score for each subscale at each time point.

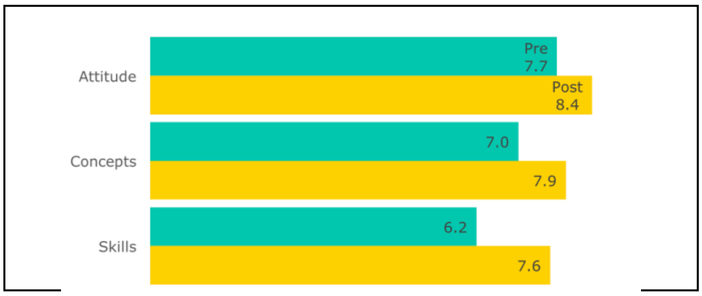

Fig. 1. Average Student Scores (N=20)

Using open coding [17], we analyzed the students' responses to some of the open-ended survey questions and focus group data. Within the domain of content knowledge, the three themes that emerged from coding students' responses were (a) *engineering in context*, (b) *problem solving*, and (c) *foundational understanding*. Within the domain of engineering affect, the two themes that emerged from coding students' responses were (a) *decision making* and (b) *feelings*.

For the *engineering in context* theme, students wrote specifically about the impact of learning physics and mathematics in the context of engineering, enhancing their knowledge of engineering within the context of exploring engineering majors and career, and being introduced to engineering in the context of "daily life" and "real world applications." Within the theme of *foundational understanding*, students wrote specifically about their desire to enhance their understanding of physics, mathematics, engineering, and engineering careers. Categorized under the theme of *problem solving*, students spoke specifically about enhancing their ability to think critically, and solve math and physics problems. The theme of *decision making* emerged as students discussed how the courses assisted them with making decisions about their engineering program of study and future career. Students expressed their *feelings* toward the courses as they spoke about their appreciation and love of engineering, or their uncertainty about their continuation with the new sequence of courses and future as engineers.

During the focus group sessions, the salient features of the courses that impacted student cognition and affect emerged as students reflected on their lived experiences. Students described the faculty as "committed" and "approachable" because they were responsive to student questions during class, held flexible office hours, explained the course goals and alignment of the assessments to those goals, and expressed genuine interest in the students' success. The students also noted the abundant resources available, such as tutoring, help from the teaching assistants, and effective course management tools that provide timely formative feedback. Almost all students who participated in the focus groups indicated that participation in the new EGR courses has increased or solidified their interest in engineering. At the time of writing this paper, we are nearing the end of the first academic year, out of the total 46 students enrolled who took at least one of the new courses, 2 have left the engineering program. One student decided to switch to a natural science major, and the other to public policy and affairs.

VI. Future Work

Future work will focus on studying the students' experiences during their sophomore year, as well as delving deeper into the data from their freshman year. Both approaches will better enable us to address how the responses to the four research questions evolve over time. We have already begun to explore how students' content knowledge was impacted by EGR 151 by looking at their performance on class assessments around key learning objectives. A cluster analysis will divide students into groups with similar experiences in their assessments, allowing the research team to better track learning gains. We will implement post-surveys following the end of the Spring 2018, Fall 2018, and Spring 2019 semesters, and will have focus groups during the latter two semesters (Spring 2018 focus groups are included in this paper). Finally, we will track enrollment data through Fall 2019 to determine retention rates for comparison with previous retention rates described above.

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