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WIP: Evaluating the impact of an introductory first-year engineering design course in shaping students' experience and academic preparedness

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WIP: Evaluating the impact of a cross-disciplinary introductory first-year engineering design course on students' attrition rates

Abstract

This Work-in-Progress paper assesses the impact of a cross-disciplinary first-year engineering design course on student retention. Engineering programs suffer from extraordinarily high attrition rates, where approximately half of the students change their major to a non-engineering one before graduation. While many factors underlie one's choice to change majors, it is possible that first-year engineering students enter their degree studies with no knowledge of the engineering disciplines and professional paths they offer, and find that their selected major is misaligned with their interests and values. Introductory engineering courses, which are commonly taken during the first semester of the engineering degree, represent an opportunity to acquaint first-year students with different engineering disciplines. Although many of these courses aim to introduce students to a single engineering discipline and excite them about it, they could be expanded to first-year students across engineering majors and teach them about the different engineering disciplines in one classroom. Such cross-disciplinary introductory courses have the potential to inform students about their choice of major, encourage switching majors within engineering, and reduce drop-out rates for non-engineering majors overall. Herein, we design a study that aims to answer whether cross-disciplinary introductory engineering courses better prepare students for their academic journey than discipline-specific courses, and promote student retention in engineering. The study compares two introductory engineering design courses that are offered in our institution, one catering to students from a single engineering discipline (mechanical engineering) and another that is cross-disciplinary. Surveys are developed to quantify students' comprehension of their selected major, their attitudes toward it, and whether they contemplate switching majors within or outside of engineering. The surveys will be administered in three phases of students' first year: before taking the introductory course, at the end of it, and at the end of their subsequent semester. In addition to surveys, students' grades and rates of attrition within and outside of engineering will be recorded. The data will be analyzed using generalized linear mixed-effects models and through a causal inference framework. The study will be validated and launched by the authors in the next academic cycle. Through this WIP paper, the authors seek to collect constructive feedback, and potentially expand this study beyond their institution.

Keywords: Causal Inference, Cross-Disciplinary Courses, First-Year Engineering Design Courses, Student Attrition.

Introduction

This work-in-progress study examines whether cross-disciplinary introductory engineering courses affect student engagement and student retention in engineering programs. Introductory courses for first-year students are essential components of collegiate engineering programs. Although high schools increasingly integrate engineering into their curricula [1], introductory engineering courses are often where students first become acquainted with the foundational principles of engineering. As such, these courses aim to shape students' initial impression of engineering and excite them about it [2], [3]. Beyond exposing students to engineering, introductory engineering courses are typically structured to establish an academic environment, develop critical study skills, instill the engineering culture, and promote camaraderie among peers toward success in subsequent coursework [4], [5], [6], [7].

Introductory engineering courses have been demonstrated to boost students' retention rates within their academic track [8], yet attrition remains a challenge in engineering majors [9]. It is estimated that approximately fifty percent of students who begin their studies in engineering switch to a non-engineering major before graduation [10], [11], [12], and half of this attrition takes place during the first year [9], [10], [12]. Research has shown that many factors underlie students' choice to switch majors from engineering to a non-engineering one. For example, the transition from high school to university often disrupts students' relationships with family and relatives whom they had relied on for time management and task prioritization [12]. Insufficient preparation in science and mathematics was also proposed to contribute to attrition in engineering [9], [11]. Relatedly, students' sense of self-efficacy [13], [14] and confidence in understanding engineering topics is tightly linked to their decision to remain in a degree course [15]. In addition, students may not identify with the culture surrounding engineering [9], [16], [17] nor develop a "sense of belonging" to the engineering field [7], [18], and seek alternative vocations. The lack of belonging particularly affects students from groups that are underrepresented in engineering, who report leaving their major due to fear of being judged by peers based on negative stereotypes [7], [19], [20].

A potential, less explored factor that could contribute to attrition is students' lack of understanding of engineering [18]. In particular, many entering students may not know what engineering entails and are not familiar with the different paths it offers. They select a discipline within engineering (for example, biomedical engineering or civil engineering) without learning about alternative engineering disciplines that better align with their intellectual interests and personal values [11]. As support for this conjecture, many students, whether they persist in engineering or not, have reported that they find engineering is broader than they had anticipated [21].

In tandem with students' understanding of their chosen engineering discipline, their "engineering identity" is typically formed [22]. The engineering identity involves the perception of oneself in the field of engineering relative to others, namely how one's competence is perceived by oneself and by their peers [22], [23]. Students' engineering identity can be decomposed into three distinct constructs [22]: i) belief in one's ability to understand engineering content and perform engineering tasks, ii) interest in performing well in engineering, and iii) feeling recognized by others as high performers in matters of engineering. These three components facilitate persistence in an engineering major [23] and navigating career paths [24]. Despite its importance, many engineering students report a struggle to develop their engineering identity, which challenges their self-efficacy and desire to complete a degree in engineering [21].

Since the first year of college appears to be critical for interventions on retention, introductory courses offer a viable opportunity to familiarize entering students with a variety of engineering disciplines. However, due to institutional and logistical limitations (e.g., difficulty in developing and coordinating requisite cross-departmental courses), introductory engineering courses are commonly offered for individual disciplines. By incorporating cross-disciplinary content early in the curriculum, first-year students could become informed regarding their options within engineering and select majors accordingly, thereby improving retention within the engineering program to some extent. Few studies have investigated this notion methodically. Orr et al. contrasted the retention rates of 977,950 students in 11 large public universities, some of whom were required to complete a cross-disciplinary Introduction to Engineering course before choosing their major, and some were not [25]. The study revealed that retention rates were higher among programs that required the cross-disciplinary course. Hoit and Ohland reported on a lecture-based Introduction to Engineering course at the University of Florida that was converted to a laboratory format where students rotated through each of the undergraduate engineering disciplines [26]. They observed a 17% improvement in retention rates with the lab-based course.

At New Jersey Institute of Technology (NJIT), the Fundamentals of Engineering Design (FED) course serves as an ideal platform to investigate how cross-disciplinary introductory courses can help reduce student attrition rates. This introductory course is a core requirement across all engineering curricula at the university and has been designed using a modular approach. Offered as a two-credit course, it is available in two formats: discipline-specific and cross-disciplinary. The discipline-specific sections are tailored for students majoring in Mechanical Engineering and Electrical Engineering. In contrast, the cross-disciplinary sections cover the contents of all engineering disciplines but are open to students from other engineering disciplines, including Biomedical Engineering, Chemical Engineering, Civil Engineering, Computer Engineering, Engineering Technology, General Engineering, and Industrial Engineering. NJIT students enter a specific engineering discipline upon admission, except for General Engineering students. General Engineering houses students who are undecided on their major and those who are underprepared for engineering study based on their application data. According to [27], this would be classified as Direct Matriculation - All Majors, where students are admitted to a specific engineering discipline and are required to take an introductory engineering course in their first term.

As described in [28], introductory engineering courses vary significantly across institutions and even within departments in an institution. A taxonomy was created to categorize the topics that are typically found in these courses and support the communication and development of curricula. The eight topics include communication, the engineering profession, math skills and application, design, global interest, professional skills, academic success, and engineering-specific technology/tools [28]. At NJIT, the cross-disciplinary FED course covers all eight categories. It features engaging and comprehensive lessons designed to provide students with a strong foundation in engineering principles, practices, and the design process. Through a combination of theoretical instruction, culturally responsive teaching, and hands-on experiences, students develop critical skills in design thinking, effective communication, and the use of engineering tools. A key component of the course involves laboratory sessions held in a state-of-the-art makerspace, where students have access to advanced equipment and resources to prototype and test their designs. The discipline-specific courses feature some categories from the eight listed above, but not all. Their focus is on providing engineering-specific technology/tools to their students, which will help them in future courses in their respective disciplines.

Throughout the semester, students participate in coursework, practical learning activities, and structured discussions. Working in multidisciplinary teams, they tackle open-ended engineering projects that emphasize the practical application of the design process. These projects focus on solving real-world challenges and fostering innovation. The hands-on challenges in the makerspace further enhance their ability to conceptualize, create, and refine their designs. Additionally, the course equips students with essential skills in computer-aided design, simulation, technical writing, oral presentations, and project management, ensuring they are well-prepared for future academic and professional pursuits.

In this WIP paper, we propose a study to quantitatively assess the success of the cross-disciplinary course in motivating students at NJIT to persist in engineering, relative to the discipline-specific courses. In particular, the study aims to answer the following hypotheses:

1. Students who complete the cross-disciplinary course are more likely to persist in their engineering studies than their peers who enrolled in a discipline-specific course.
2. Students who completed the cross-disciplinary program have a better understanding of their selected major, compared to their peers who enrolled in the discipline-specific introductory course.
3. Students who completed the cross-disciplinary program are more satisfied with their choice of major and feel like they belong to it, compared to their peers who enrolled in the discipline-specific introductory course.
4. The students enrolled in the cross-disciplinary course are more likely to switch to a different engineering major than the students enrolled in a discipline-specific course.

5. The students who completed a discipline-specific course are more likely to switch to a non-engineering major than their peers who completed the cross-disciplinary course.

To test these hypotheses, we develop a survey that quantifies first-year engineering students' comprehension of their selected major, attitudes towards it, and their intention and sense of self-efficacy in pursuing it. For a complete analysis, survey data are complemented by students' records of academic performance and academic advising, and demographic and socioeconomic information. After the data are collected, we propose two approaches to analyze them. The first analysis will capture statistical trends using generalized linear-mixed effects models [29]. The second analysis will employ counterfactual-based causal inference to establish the causal role of the introductory course in observed outcomes.

The proposed study will be implemented in the next academic cycle at our institution. We will collect preliminary data in Spring 2025 to validate the surveys and analyses. To ensure that the length of the survey is appropriate, we will also consider the necessity and redundancy of the questions. Upon approval of the protocol by an Institutional Review Board, we will collect data with the cohort of Fall 2025. Should the study be successful, the methods will be generalized to maximize the outcomes of cross-disciplinary first-year programs in other programs and institutions.

Methods

Survey Development

We developed a set of three surveys that will be administered to first-year students (Table 1). Responses to the first survey will measure students' familiarity with their selected major (Questions 1-7), establish their baseline self-efficacy (Questions 8-18), and assess their attitudes toward engineering (Questions 19-35). In particular, Questions 19-22 will quantify respondents' commitment to completing a degree in engineering, Questions 23-29 will assess the presence and use of a support system and independence in decision-making, and Questions 30-35 will measure respondents' initial identification with engineering.

The second survey will gauge whether the introductory engineering design course improved respondents' familiarity with their selected major (Questions 1-3), left impressions on their sense of self-efficacy (Questions 8-18), and influenced their commitment to pursue their degree (Questions 19-22, 58-60, 62-63). Like the first survey, we will re-evaluate students' use of their support system in decision-making (Questions 26-29) and identification with engineering (Questions 30-41). In addition, we will measure students' sense of belonging to the university, their major, and engineering as a whole (Questions 42-52, 61), and identification with the engineering culture (Questions 53-57).

The third survey will measure the course's influence on long-term behavior and academic choices. The survey will be structured similarly to the second survey, only it will also ask respondents to reflect on the contents of the introductory course and identify elements that contributed to their academic success in the subsequent semester (Question 64).

Data Collection

Surveys are planned for three different stages of students' first-year studies. The first survey will be administered in class during the first lecture before the students are introduced to any engineering-related topic. The second survey will be administered in class during the final lecture of the course. The third survey will be administered online at the end of the following Spring semester.

In the Fall semester, approximately 610 students will enroll in our FED courses. About 330 of them will enroll in the discipline-specific course (150 in three sections for electrical and computer engineering, and 180 in six sections for mechanical engineering). The remaining 280 students will enroll in the cross-disciplinary course, which includes two sections of 90 students, one section of 60 students, and one smaller section of 40 students designated for honors students. The honors section is distinguished by its inclusion of more advanced projects that challenge students to apply higher-level critical thinking and engineering skills. Although we anticipate a high response rate for the first and second surveys that will take place in class, the third survey will likely produce only 268 responses (124 from the cross-disciplinary course and 145 from the discipline-specific course) [30], [31]. To further incentivize participation in the study, students who complete the first two surveys will receive two points toward their course grade. Among students who participate in the third survey, a gift card will be raffled.

In addition to students' survey responses, demographic and socioeconomic information, academic records, and retention rates within engineering majors will be collected. Demographic information will include students' age, sex, gender, race, and ethnicity. Socioeconomic information will include parents' income, education level, employment, and marital status. Finally, the academic records will contain students' majors and grades in the courses taken during their first two semesters.

Data Analysis

Data analysis will be conducted using two approaches. In the first analysis, each of the hypotheses we put forth will be tested using a generalized linear mixed effects model [29]. This statistical approach allows us to account for nested groups within the sample by including random and fixed effects in a model. Retention (or intent to remain) in an engineering degree track and self-efficacy will be modeled as outcome variables. Students' initial choice of a major, which may be associated with a varied perceived level of difficulty [30] will be treated as a fixed effect. The section students are enrolled in will be incorporated as a fixed effect as well, as each section will be taught by a different instructor, and content will be presented differently. Finally, demographics and socioeconomic circumstances will be specified as random effects. The significance of the influence of random and fixed effects will be tested using a likelihood ratio test, comparing the model against a null model.

In the second analysis, we will aim to pinpoint the causal role of the cross-disciplinary content in improving retention (and not other confounding factors) using the counterfactual-based causal inference framework of Difference-in-Differences [31], [32]. Difference-in-differences is a research design commonly used in medicine, epidemiology, and econometrics. It compares the change in outcome in a treated group and an untreated group, before and after a given treatment. As such, it requires measurements from both groups (designated “'treatment” and “control”, respectively) before and after the treatment (designated “pre” and “post”, respectively). In our setting, the retention rate is the outcome, the cross-disciplinary course is the treatment, and the discipline-specific course is the control. The surveys will be strategically administered before and after the courses to obtain “pre” and “post” measurements.

We will perform the following regression:

$$y_{i,t} = \beta_0 + \beta_1 \cdot x_i + \beta_2 \cdot x_t + \beta_3 \cdot x_{i,t} + \epsilon_{i,t},$$

where $y_{i,t}$ is the outcome variable for each student (for example, remaining or leaving their major); x_i is a dummy variable indicating whether the student belongs to the treated or untreated group (that is, whether they enrolled in the discipline-specific or cross-disciplinary introductory course); x_t is a dummy variable indicating whether the observation was made before or after the student completed the FED course; $x_{i,t}$ is a dummy variable of the interaction between the treatment and its timing; and $\epsilon_{i,t}$ is a white noise error term. The regression will estimate the coefficients β_0, β_1, β_2, and β_3, where we hypothesize that β_3 is statistically different from zero to establish a causal relationship.

Discussion

This paper makes substantial contributions to engineering education by delivering a thorough assessment of cross-disciplinary introductory courses and their capacity to decrease attrition rates in engineering programs. This research mitigates confounding variables associated with institutional variations by comparing the outcomes of discipline-specific and cross-disciplinary courses within the same institution. Moreover, employing both statistical and causal inference approaches guarantees a rigorous analysis, allowing the study to produce actionable insights that can be scaled and adapted to other engineering programs.

The proposed study is not without its limitations. One primary concern is the potential for bias in self-reported data collected through surveys. While the surveys are designed to assess students' comprehension, attitudes, and self-efficacy, responses may not always reflect their actual understanding or intentions. Additionally, the study does not control for pre-existing differences among students that might influence outcomes, such as varying levels of prior exposure to engineering concepts, academic preparedness, or personal circumstances. Furthermore, the causal inference framework, while robust, may not fully account for unobserved confounding variables, such as peer influence or the quality of teaching, which could impact the retention rates and perceptions of both groups.

Moreover, while NJIT is moving in the direction of making this a universal experience for all students, the transition remains gradual and requires departmental buy-in. As an initial step to support this shift, we are proposing to the departments in question to allow students the option to choose between a disciplinary-specific or cross-disciplinary approach. This phased implementation not only helps the department ease into the transition but also provides students with the opportunity to select the format that best aligns with their interests and learning preferences. Additionally, allowing honors students the flexibility to choose between the discipline-specific or cross-disciplinary focused version of the course ensures their academic strengths and goals are supported, contributing to a smoother integration of the new framework.

Another limitation is the study's exclusion of certain variables that could significantly affect the results. For instance, the survey does not specifically address external factors like financial pressures, family responsibilities, or cultural barriers that may disproportionately impact retention. Moreover, the study does not include longitudinal tracking beyond the first year, limiting insights into whether the benefits of the cross-disciplinary course persist throughout students' academic journeys. Differences in instructor teaching styles and classroom environments, which could influence student engagement and satisfaction, are also not directly evaluated.

Despite these challenges, the study identifies promising opportunities for next steps. A critical area for improvement is expanding the dataset to include more diverse student populations across multiple institutions, which would increase the generalizability of the findings. Additional qualitative methods, such as interviews or focus groups, could complement the surveys, providing richer insights into students' experiences and the barriers they face. Moreover, integrating adaptive learning tools and feedback mechanisms into the courses could enhance the instructional quality and allow for iterative improvements based on student needs. These enhancements will strengthen the study's capacity to inform the development of cross-disciplinary introductory courses that support student retention and success in engineering programs.

Table 1. A list of questions that the three surveys comprise. The first column itemizes the 64 questions. The second column corresponds to the sequential timing of the three surveys that will be administered: before taking the course (Survey 1), at the end of the course (Survey 2), and at

the end of the subsequent semester (Survey 3). The third column contains the questions that will be presented to participants, along with references to past studies they were borrowed from. The fourth column contains the expected response type.

#	Survey	Question	Response
1	1,2,3	I have a good understanding of what my major entails.	7-point Likert scale
2	1,2,3	I know what careers I can pursue after I graduate with a degree in my major	7-point Likert scale
3	1,2,3	I can see myself with an engineering career in my major of choice.	7-point Likert scale
4	1	I know several engineers.	7-point Likert scale
5	1	A member of my family and/or a friend is an engineer. [18]	Yes No
6	1	A member of my family and/or a friend recommended that I pursue engineering. [18]	Yes No
7	1	I have had previous exposure to engineering through (check all that apply): [33]	Science and math classes Technology or engineering courses Presentations and seminars Field trips Other
8	1,2,3	When I make plans, I am certain I can make them work. [14]	7-point Likert scale
9	1,2,3	One of my problems is that I cannot get down to work when I need to. [14]	7-point Likert scale
10	1,2,3	If I can't do a job the first time, I keep trying until I can. [14]	7-point Likert scale
11	1,2,3	I give up on things before completing them. [14]	7-point Likert scale
12	1,2,3	I avoid facing difficulties. [14]	7-point Likert scale
13	1,2,3	When I decide to do something, I go right to work on it. [14]	7-point Likert scale
14	1,2,3	I avoid trying to learn new things when they look too difficult for me. [14]	7-point Likert scale
15	1,2,3	Failure just makes me try harder. [14]	7-point Likert scale

16	1,2,3	I feel insecure about my ability to do things. [14]	7-point Likert scale
17	1,2,3	I am a self-reliant person. [14]	7-point Likert scale
18	1,2,3	I can complete a degree in my selected major.	7-point Likert scale
19	1,2,3	I intend to complete a degree in my selected major. [17]	7-point Likert scale
20	1,2,3	I have no desire to declare a non-engineering major. [17]	7-point Likert scale
21	1,2,3	I can think of other majors that I would like better than engineering. [17]	7-point Likert scale
22	1,2,3	Obtaining a degree in another field is interesting to me.	7-point Likert scale
23	1	I have family and friends who give me advice on school and managing my time.	Yes No
24	1	I value the advice I receive from family and friends about school and time management.	7-point Likert scale
25	1	I often follow the advice I receive from family and friends.	7-point Likert scale
26	1,2,3	I follow the advice I receive from my academic advisor.	7-point Likert scale
27	1,2,3	I feel like I have sufficient guidance from my academic advisor in my choice of major. [11]	7-point Likert scale
28	1,2,3	I am satisfied with the support I receive from my academic advisor. [17]	7-point Likert scale
29	1,2,3	Number of times I met with my academic advisor	Free text
30	1,2,3	I like the work that engineers do. [34]	7-point Likert scale
31	1,2,3	The “engineering way of thinking” (e.g., problem-solving and critical thinking) is appealing to me. [33]	7-point Likert scale
32	1,2,3	The “hands-on” nature of engineering (e.g., building and design) is appealing to me. [33]	7-point Likert scale
33	1,2,3	I am interested in learning more about engineering. [22]	7-point Likert scale
34	1,2,3	I am confident that I can understand engineering in class. [22]	7-point Likert scale

35	1,2,3	I am confident that I can understand engineering outside of class. [22]	7-point Likert scale
36	2,3	I find fulfillment in doing engineering. [22]	7-point Likert scale
37	2,3	I understand the concepts I have studied in engineering. [22]	7-point Likert scale
38	2,3	Others ask me for help on this subject. [22]	7-point Likert scale
39	2,3	My family sees me as an engineer. [22]	7-point Likert scale
40	2,3	My peers see me as an engineer. [22]	7-point Likert scale
41	2,3	I have had experiences in which I was recognized as an engineer. [22]	7-point Likert scale
42	2,3	I feel a sense of belonging to NJIT. [35], [36]	7-point Likert scale
43	2,3	I feel a sense of belonging in my major. [35]	7-point Likert scale
44	2,3	I feel that I am a member of NJIT's community. [35], [36]	7-point Likert scale
45	2,3	I feel that I am a member of my academic major's community. [36]	7-point Likert scale
46	2,3	I feel comfortable on campus. [35], [36]	7-point Likert scale
47	2,3	If given the opportunity, I would choose to attend NJIT again. [35], [36]	7-point Likert scale
48	2,3	If given the opportunity, I would choose my academic major again. [35], [36]	7-point Likert scale
49	2,3	My college is supportive of me. [35], [36]	7-point Likert scale
50	2,3	My academic major's community is supportive of me. [36]	7-point Likert scale
51	2,3	I feel a sense of belonging to engineering.	7-point Likert scale
52	2,3	I feel like I am a part of an engineering community. [17]	7-point Likert scale
53	2,3	The culture in engineering is appealing to me.	7-point Likert scale

54	2,3	I like studying with other students in a group. [17]	7-point Likert scale
55	2,3	I am involved with student study groups. [17]	7-point Likert scale
56	2,3	I enjoy spending time with engineering students. [37]	7-point Likert scale
57	2,3	Engineering students help each other succeed in class. [17]	7-point Likert scale
58	2,3	I am confident in my ability to succeed in my college engineering course. [17]	7-point Likert scale
59	2,3	Compared to other students in my classes, I think my academic abilities in my engineering courses are far above average. [17]	7-point Likert scale
60	2,3	Compared to other students in my classes, I think my academic abilities in my engineering courses are far below average. [17]	7-point Likert scale
61	2,3	I feel like an engineer. [38]	7-point Likert scale
62A	2,3	I have contemplated switching to another major in engineering.	7-point Likert scale
62B	2,3	If yes, which major?	Free text
63A	2,3	I have contemplated switching to a non-engineering major.	7-point Likert scale
63B	2,3	If yes, which major?	Free text
64	3	The following modules of the course helped me prepare for my college studies (select all that apply):	Becoming the Best Engineering Student Engineering Design Process Be the Engineer Activity Engineering Practice: Engineering Success Case Studies Conducting Engineering Research Engineering Documentation Ethics, Inclusive Design, and DEIB Considerations in Engineering Engineering Practice: Societal Impact Engineering Product DEIB Analysis

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