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Investigating the Impact of First-Year Course Activities on Students' Identity and Sense of Belonging in Engineering and Computing

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ABSTRACT

The purpose of this research paper is to understand the impact of an interdisciplinary project-based first-year engineering and computing course sequence on students' development of engineering/computing identity and sense of belonging in these disciplines.

Developing an identity as an engineer or computer scientist, and developing a sense of belonging in these fields, are critical for student retention and success. Recent research on why undergraduates leave STEM disciplines confirms earlier findings, which showed that many students who leave do so for reasons that are unrelated to meeting the intellectual demands of STEM disciplines. For many students, particularly women and minoritized individuals, issues related to climate, lack of fit, and a lack of developing an engineering identity early in their matriculation can be significant drivers of attrition from technical fields. Previous research suggests that project-based learning builds students' engineering/computing identity by piquing and developing student interest in engineering topics. Literature on the sense of belonging in engineering suggests that experiencing camaraderie within course-based teams, and particularly having a clear purpose or role within the team, can promote that sense of belonging. The current research project sought to implement evidence-based practices to enhance first-year students' identity and sense of belonging in engineering and computing, in the context of a two-semester introductory course sequence that integrates students from across all engineering and computing majors within the college of engineering and computing at an undergraduate-focused national public university in the midwest. The goal of the study is to assess the effects of the new first year-course sequence on students' identity as engineers/computer scientists and students' sense of belonging in engineering and computing disciplines.

The two-semester course sequence was implemented in pilot form in Fall 2022/Spring 2023. Research methods were reviewed and approved by the university's institutional review board. A subset of entering first-year students were randomly selected for enrollment in the pilot course sections, and the remaining entering first-year students were enrolled in the existing department-specific introductory engineering or computing courses that have traditionally served incoming engineering and computing students in their respective disciplines. Published survey instruments were used to assess engineering/computing identity and sense of belonging for students in the pilot course sequence and the traditional course sequence. Surveys were

administered at the start of the fall semester, at the end of fall semester, and at the conclusion of the spring semester. There were a total of 301 respondents for the pre-course survey, 97 respondents for the mid-point survey, and 235 respondents for the final survey. Responses were de-identified and student identities were protected. Pseudo-IDs were generated to enable analysis of changes in individual student responses over time. Administered survey instrument responses were analyzed using mixed model analysis of variance (ANOVA) techniques, with track (traditional vs project-based, 2 levels) as a between-subjects effect and stage (start of year, end of year) as a within-subjects effect.

Engineering identity was compared between students who participated in the pilot course sequence and students who participated in the original course sequence. Engineering identity was measured to be higher in the students who participated in the pilot sequence compared to the students who participated in the traditional sequence. Additionally, measures of belongingness also increased for students in the pilot program while they decreased in students who participated in the original course sequence. Qualitative survey responses suggest that students in the pilot course valued the design/build projects that applied technical concepts, receiving encouragement from professors, and contributing their own knowledge to the work of the team. Future work will quantify the impact of the pilot course sequence on retention and further investigate the implications of the interdisciplinary nature of the course on student team dynamics and identity development.

Motivation and Background

National reports have argued that attracting and retaining more students in STEM fields is important to meet future workforce needs and to ensure the economic strength and global competitiveness of the U.S. [1,2]. Other analyses frame the argument in terms of an ever-expanding need for graduates with strong STEM competencies, independent of the specific career path chosen [3]. Analyses of two national data sources, NCES and CIRP, suggest that 28% of STEM majors switch into non-STEM majors, and an additional 20% of STEM majors leave their institution without a degree [4-6]. This means that only 52% of students who enter a STEM major complete a STEM degree [4].

Recent research on why undergraduates leave STEM disciplines confirms earlier findings, which showed that many students who leave do so for reasons that are unrelated to meeting the intellectual demands of STEM disciplines. In 1997, Seymour and Hewitt analyzed an extensive body of research that revealed several factors leading students to drop out of STEM majors [7]. Beyond inadequate preparation, the identified driving factors also included poor teaching, curriculum overload, inadequate advising and support, and rejection of the highly competitive culture in many STEM majors [8]. Similar findings were observed in Geisinger and Raman’s

2013 analysis of student attrition from engineering majors [9]. In that study, the authors examined fifty publications from literature and identified a common set of factors driving students' decisions to leave engineering majors, including an individualistic culture and reliance on traditional forms of teaching and advising, difficulty understanding the material and discouragement related to competitive grading structures, students' lack of self-efficacy or self-confidence, inadequate high school preparation, failure of engineering course material to capture student interest, and obstacles students may encounter related to gender, race, or ethnicity. More recently, Seymour and Hunter led an updated comprehensive investigation of student attraction to and retention in STEM, with data collection spanning large research institutions to small liberal arts colleges over the 5-year period from 2012-2017 [10]. This work is a follow-up study to Seymour and Hewitt [7] cited above. The updated findings showed that while many driving forces of attrition noted in the earlier 1997 study remain in effect, marked changes were noted in other factors including a large upward shift in students' negative reaction to the competitive climate experienced in STEM classes, increased reports of loss of confidence including among high-performing female students who switch out of STEM, and problems financing college. Seymour also notes that students with socio-economic disadvantages are at risk of leaving their institution following just one DFWI grade in a severe STEM gateway course even when their grades in other courses place them in good academic standing [4]. This body of literature suggests that for many students, particularly women, minoritized individuals, and students from disadvantaged backgrounds, issues related to competitive/individualistic climate, lack of fit, lack of interest, and loss of self-efficacy can be significant drivers of attrition from technical fields.

The themes emerging from this analysis are closely related to the concept of engineering identity, as well as to the conditions that may contribute to a student's sense of belonging in STEM. Researchers have noted that development of an engineering identity goes beyond learning the technical skills and knowledge of the discipline, it also includes "aligning one's sense of self with the field of engineering" [11]. Godwin's [12] assessment instrument for measuring the development of engineering identity encompasses students' self-beliefs of their interest, performance/competence, and recognition within engineering. Prior research suggests that project-based learning builds students' engineering identity by piquing and developing student interest in engineering topics [13]. Studies have shown that engineering identity precedes persistence in engineering degree programs [14,15] and that engineering identity is a significant predictor of retention in engineering [11].

Sense of belonging has been defined as "the degree to which an individual feels respected, valued, accepted, and needed by a defined group" [16]. Sense of belonging is a key predictor of student success [17] and is associated with positive factors such as increased motivation, self-efficacy, and mental health [18-20]. Research also shows that instructors can promote a sense of belonging by encouraging student collaboration and engagement through well-designed courses [18, 20, 21]. For example, literature on the sense of belonging in engineering suggests that experiencing camaraderie within course-based teams, and particularly having a clear purpose or role within the team, can promote that sense of belonging [20].

The current research project sought to implement evidence-based practices to enhance first-year students' identity and sense of belonging in engineering and computing, in the context of a two-semester introductory course sequence that integrates students from across all engineering and computing majors within the college of engineering and computing at an undergraduate-focused national public university in the midwest. The goal of the study is to assess the effects of the new first year-course sequence on students' identity as engineers/computer scientists and students' sense of belonging in engineering and computing disciplines.

Course Sequence

Traditional Course Sequence

For many years, the first year experience in the college of engineering has consisted of a one-credit Fall course that prepares students to be successful in college and provides students with information about the support structures on campus. The material in the course is monitored by the university and students across the university take a similar course across other divisions of the university. Although some engineering faculty have taught the course in the past, more recently, professional advisors in the college of engineering or staff directly connected with the college have taught the course. The course does discuss engineering ethics and requires the engineering students to engage in engineering-specific programming on occasion, however, much of the content is general to the university and the undergraduate experience. All students at the university are required to take this course or a similar one their first semester at the university.

In the Spring, students would then take a three-credit introductory course that was hosted and managed by each department within the college. Each department was responsible for the curriculum in this course and many departments used this course to introduce students to software and tools that would be leveraged in higher-level courses. Students were encouraged to take the course that aligned with their desired engineering or computer science major, however, each of the departmental courses "counted" for each other so that students who changed their majors within the college were not delayed.

Although this course structure did allow for significant flexibility and autonomy within the departments, there were some consistent issues with the structure. First, students expressed a lack of connection to the college in their first semester because the Fall course focused on providing university-wide information and spent little time discussing engineering-related content.

Secondly, because each department was able to determine the content and structure of the Spring course, the workload and expectations on the students varied widely across the college which led to significant frustrations. Lastly, although students had the ability to switch majors without having to take a second introduction course, the students who switched majors would frequently express feeling under-prepared for their new major as critical material was introduced in the introductory course they did not take.

Pilot Course Sequence

A new first-year curriculum was developed with the intent of addressing the issues that occurred with the traditional course sequence. The new curriculum consists of two, two-credit hour courses, one taken in the Fall and one taken in the Spring semester. Both courses are team-based courses that discuss a wide range of engineering topics through their applications to multiple projects. Each course is two credits and meets for four hours a week.

In the Fall course, the university-related material is introduced to the students through the first month of class. The remaining time in the course was dedicated to four multi-disciplinary team projects, each focusing on a different discipline within the college of engineering. In the Spring course, students were introduced to programming in Python and MATLAB through required course content and then were allowed to explore and specialize with elective modules that range from CAD and 3D printing to finding hidden messages in audio files. Additionally, there is a semester-long team project where students explore applications of engineering principles through building and improving a table-top wind turbine.

Methods

The two-semester course sequence was implemented in pilot form in Fall 2022/Spring 2023. A subset of entering first-year students were randomly selected for enrollment in the pilot course sections, and the remaining entering first-year students were enrolled in the existing department-specific introductory engineering or computing courses that have traditionally served incoming engineering and computing students in their respective disciplines. Published survey instruments were used to assess engineering/computing identity [12] and sense of belonging [22] for students in the pilot course sequence (Pilot) and the traditional course sequence (Traditional). Applicable survey questions are given in the Appendix. Surveys were administered at the start of the fall semester, at the end of fall semester, and at the conclusion of the spring semester. Responses were de-identified and student identities were protected. Pseudo-IDs were generated to enable analysis of changes in individual student responses over time. Data collection methods were reviewed and approved by the university's institutional review board.

Stratified Analysis

The following are analyses stratified by engineering Identity (Recognition, Interest, Performance/Competence) and Belongingness.

There were 418 unique students who participated in the survey across the three stages (Sep 2022, Dec 2022, May 2023). However, an analysis of response profiles revealed that:

- 240 students only responded once across the three stages (57%)
- 141 students responded twice across the three stages (127 of them were in Sep 2022 and May 2023)
- Only 37 students responded across all three stages (9%)

There was very low student response in the traditional course at the Dec 2022 stage. As a result, only student responses from Sep 2022 and May 2023 were used in the analyses. The remaining subjects who failed to respond in one of either Sep 2022 or May 2023, and all subsequent analyses assume that these are missing at random (MAR).

Student-level response scoring for each endpoint (Recognition, Interest, Performance/Competence, Belongingness) is the mean of the 5-point Likert scale of the corresponding survey items. For each endpoint, descriptive sample statistics (mean, standard error, etc) were calculated for each course sequence at both stages (Sep 2022, May 2023). Separate mixed effects ANOVA models were fit using each engineering identity endpoint score (Recognition, Interest, Performance/Competence) and Belongingness as response variables, Stage (Sep 2022, May 2023) as the two-level within-subjects (repeated) factor, and course sequence (Traditional, Pilot) as the two-level between-subjects factor. Follow-up sequence-specific comparisons of change from Sep 2022 to May 2023 were also performed. Assumptions of normality and homogeneous error variance were checked and verified.

All analyses were performed in R version 4.2.1[23], using add-on libraries tidyverse, knitr, lme4, and emmeans.

Identity Comparison Analysis

In addition to looking at the measures in a stratified way, identity and its three sub-constructs were evaluated more deeply. The mean scale responses between the engineering identity endpoints were compared using the same subject pool as in the previous stratified analyses. A mixed effects ANOVA model was fit using engineering identity score as the response variable; engineering identity dimension (3 levels: Recognition, Interest, Performance/Competence) and stage (2 levels: Sep 2022, May 2023) as within-subjects (repeated) factors, and course sequence (Traditional, Pilot) as the two-level between-subjects factor in a full factorial structure. Sphericity was checked and test results adjusted as necessary.

Results

Stratified Analysis

The resulting sample sizes by course sequence vary by endpoint and may be seen in the summary table below (**Table 1**).

Table 1: Summary of the mean and standard deviation for each course sequence (Traditional and Pilot), data collection time point (start of Fall 2022, end of Spring 2023), and measure (Identity - Recognition, Identity - Interest, Identity - Performance/Competence, and Belongingness)

Sequence	Stage	N	Recognition		Interest		Perf./Comp.		Belongingness	
			Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.	Mean	St. Dev.
Traditional	F 22	214	3.977	0.769	4.481	0.619	3.955	0.652	4.221	0.701
Traditional	S 23	189	3.889	0.835	4.268	0.853	3.949	0.753	4.060	0.828
Pilot	F 22	84	3.889	0.851	4.433	0.666	3.964	0.649	4.247	0.623
Pilot	S 23	44	4.030	0.715	4.530	0.539	4.150	0.566	4.385	0.592

There are no significant differences in mean Recognition change between Traditional and Pilot sequences from Sep 2022 to May 2023 (F=1.5358, df1=1, df2=185.9, p=0.2168), and post-hoc comparisons revealed no significant Recognition change within either course sequence (Traditional p-value = 0.5551; Pilot p-value = 0.2785) (**Figure 1**). Similar results were found for Performance/Competence (F=1.5911, df1=1, df2=213.2, p=0.2085) with insignificant mean change results in each sequence (Traditional p-value = 0.8683; Pilot p-value = 0.1278) (**Figure 2**). It is worth noting that, though statistically insignificant, there is some indication of improvement in the Pilot sequence in both Recognition (mean change = 0.115, effect size = 0.0788) and Performance/Competence (mean change = 0.1586, effect size = 0.1020). For the engineering identity dimension of Interest, there is some statistical evidence of a change over time between the two course sequences (**Figure 3**). In the Traditional sequence, a significant decline in Interest was observed (mean change = −0.1933, effect size = 0.2086, p-value = 0.0009) while there was no significant change observed in the Pilot sequence (mean change = −0.0293, effect size = 0.0193, p-value = 0.7789).

There is a significant difference between the two courses with regard to change in mean Belongingness (F=3.5573, df1=1, df2=214.2, p=0.0606) (**Figure 4**). In the Traditional sequence, a significant decline in Belongingness was observed (mean change = −0.1491, effect size =

0.1521, p-value = 0.0140) while there was no significant change observed in the Pilot sequence (mean change = 0.0844, effect size = 0.0523, p-value = 0.4372).

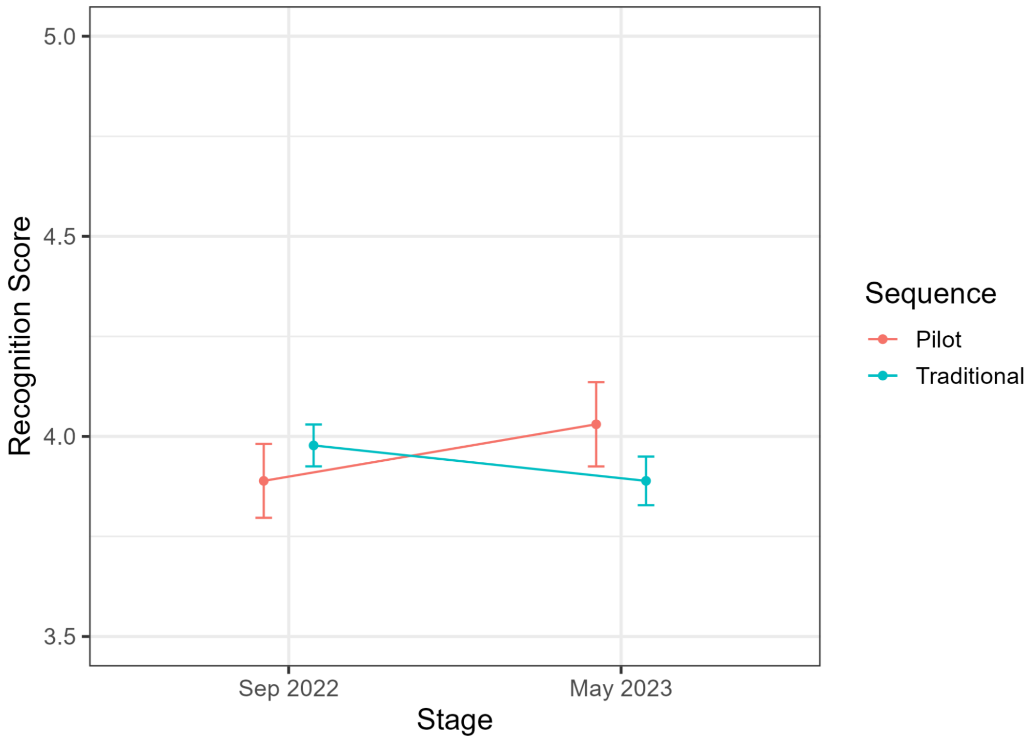

Figure 1. Engineering identity (recognition). Mean scores with standard error bars.

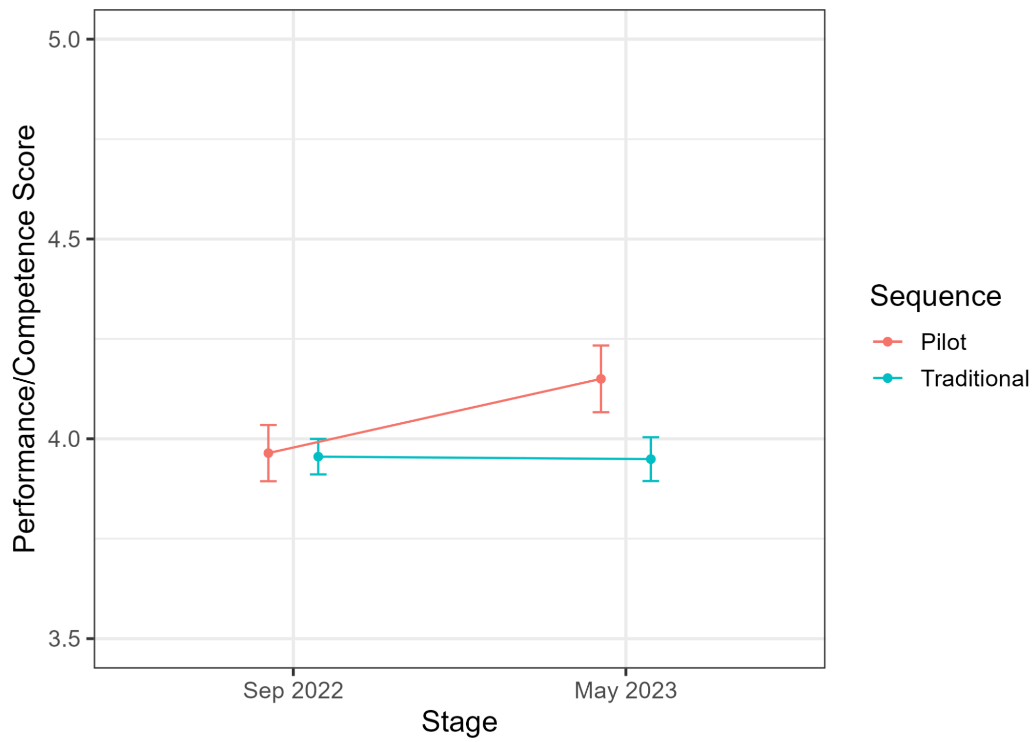

Figure 2. Engineering identity (performance/competence). Mean scores with standard error bars.

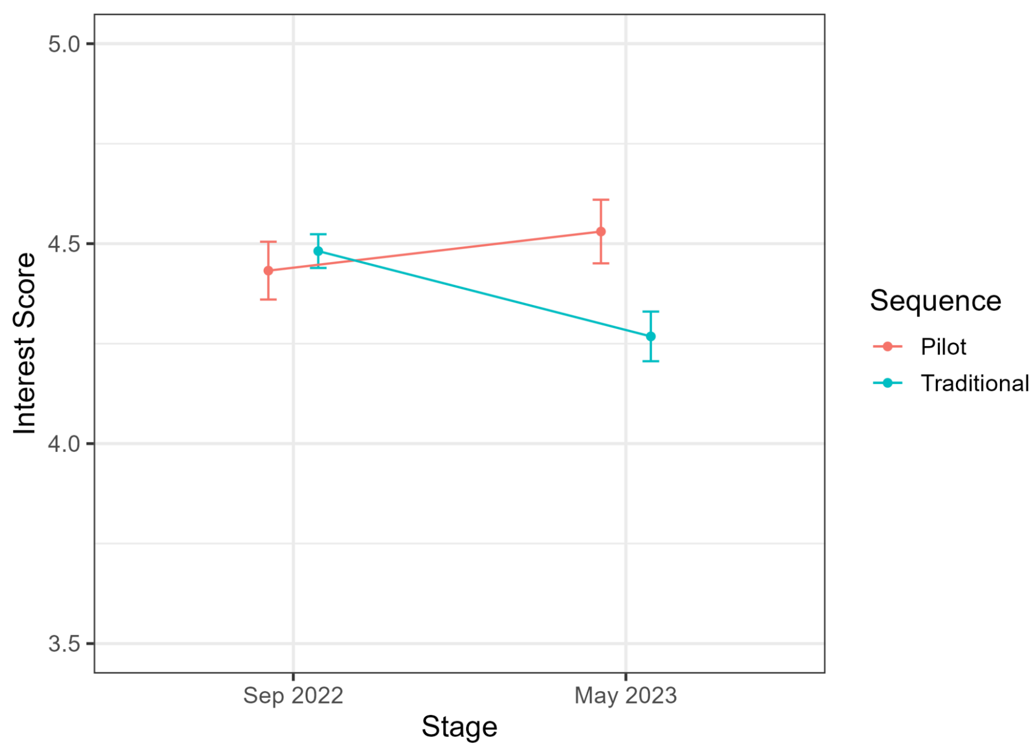

Figure 3. Engineering identity (interest). Mean scores with standard error bars.

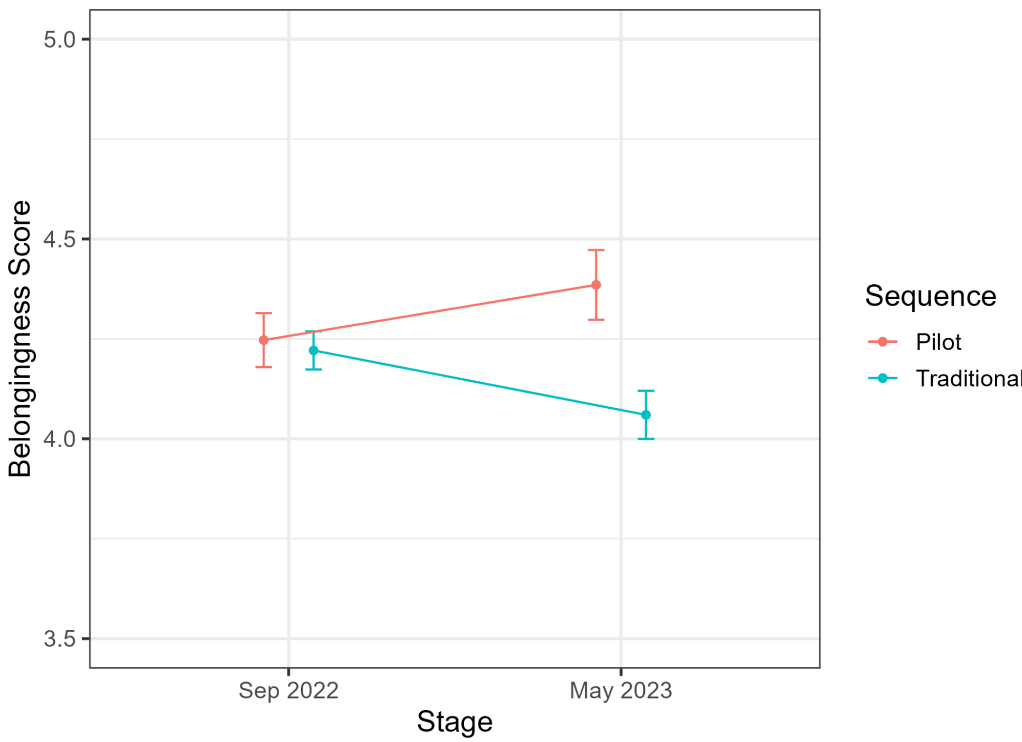

Figure 4. Sense of belonging. Mean scores with standard error bars.

Results of Identity Comparison Analysis

There was a significant difference in omnibus mean response between the different engineering identity dimensions (Likelihood ratio $\chi 2=296.47$, df=8, $p<0.0001$). Upon further investigation, the three-way interaction did not reveal that the identity effect differed significantly between different combinations of stage and course sequence (F=0.3840, df1=2, df2=1054.8, p=0.6812).

Tukey-adjusted pairwise comparisons of the three engineering identity dimensions revealed that mean scores between Performance/Competence and Recognition did not significantly differ (mean difference = 0.0591, SE = 0.035, p-value = 0.2095), but that Interest was scored significantly higher than both Performance/Competence (mean difference = 0.4234, SE = 0.035, p-value < 0.0001) and Recognition (mean difference = 0.4825, SE = 0.035, p-value < 0.0001).

Limitations

One of the potential limitations is that the new course sequence was piloted for the first time during the timeframe of the study. The discipline-specific projects were developed during the semester they were offered, and the instructors rotated through the sections of the course teaching their own project to each section of the pilot course so students experienced four unique instructors. The students were thus required to adjust to a new teaching style and new expectations for project documentation every 2.5 weeks, for four projects. The instability may have had a dampening effect on the student responses from the Fall Pilot course as compared to the Fall Traditional course.

Discussion and Conclusion

Developing an identity as an engineer or computer scientist, and developing a sense of belonging in these fields, are critical for student retention and success. The purpose of this research paper is to understand the impact of an interdisciplinary project-based first-year engineering and computing course sequence on students' development of engineering/computing identity and sense of belonging in these disciplines. Our results show a decline in the (pre- and post-) means for the Traditional sequence for all of the dimensions studied (recognition, performance/competence, interest, and belongingness) and an increase in the same for the Pilot sequence. While these differences are not all statistically significant, there is some evidence that the new course sequence had a positive (or at least non-deleterious) effect on students' perceptions of their engineering and computing identities.

The differential impact of the Traditional sequence versus the Pilot sequence on sense of belonging is intriguing. The Pilot course design intentionally placed students in teams, typically composed of 3 to 5 students from different engineering and computing majors. Students remained on the same team for approximately half of the semester (in the Fall) or the entire semester (in the Spring). Instruction was provided on elements of effective teamwork and the importance of having clear roles for each member of the team. Students were encouraged to adopt specific roles within their team in accordance with their interests. The opportunity to develop camaraderie within their teams over a period of months may have contributed to the ability of the Pilot sequence to maintain students' sense of belonging in engineering and computing, in contrast with the significant decline in belongingness observed in the Traditional sequence. An area for future improvement is to better align the team member roles with the actual tasks to be performed within the projects, rather than using general role assignments such as project manager, documentarian/recorder, presenter/spokesperson, etc. In future research we plan to continue studying the impact on engineering/computing identity and belongingness as the Pilot courses become more established and refined. We also plan to investigate the impact of the courses on retention within engineering and computing.

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APPENDIX

Table A.1: Survey items used to measure engineering/computing identity (adapted from [12])

Q16. The following questions use the term "engineer" to refer to all majors in Miami's College of Engineering and Computing, including computer science. Please keep your major in mind when answering the questions. (Response categories: Strongly disagree (1); Somewhat disagree (2); Neither agree nor disagree (3); Somewhat agree (4); Strongly agree (5))

Construct	**Question**	**Statement**
Recognition	Q16_1	My parents see me as an engineer.
	Q16_2	My instructors see me as an engineer.
	Q16_3	My peers see me as an engineer.
	Q16_4	I have had experiences in which I was recognized as an engineer.
Interest	Q16_5	I am interested in learning more about engineering.
	Q16_6	I enjoy learning engineering.
	Q16_7	I find fulfillment in doing engineering.
Performance / Competence	Q16_8	I am confident that I can understand engineering in class.
	Q16_9	I am confident that I can understand engineering outside of class.
	Q16_10	I can do well on exams in engineering.
	Q16_11	I understand concepts I have studied in engineering.
	Q16_12	Others ask me for help in this subject.
	Q16_13	I can overcome setbacks in engineering.

Table A.2: Survey items used to evaluate belongingness (adapted from [22])

Q17. The following questions use the term "engineer" to refer to all majors in Miami's College of Engineering and Computing, including computer science. Please keep your major in mind when answering the questions. (Response categories: Strongly disagree (1); Somewhat disagree (2); Neither agree nor disagree (3); Somewhat agree (4); Strongly agree (5))

Question	**Statement**
Q17_1	I feel comfortable in engineering.
Q17_2	I feel I belong in engineering.
Q17_3	I enjoy being in engineering.
Q17_4	I feel comfortable in my engineering class.
Q17_5	I feel supported in my engineering class.
Q17_6	I feel that I am part of my engineering class.