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Engineering Curriculum Rooted in Active Learning: Does It Promote Engagement and Persistence for Women?

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Structured Abstract

Background - Active, problem-based learning is increasingly being used in engineering education. Group projects to design and build devices and ethical case studies sensitize students to real world experiences. They also increase critical thinking and engagement. Research has demonstrated that short-term outcomes of an active learning pedagogy include increasing student engagement in class, improving students' examination results more than traditional courses, and ensuring more students pass the course. Long-term outcomes include increased engagement and motivation to learn, and helping students gain self-confidence and a sense of accomplishment.

Purpose/Hypothesis- The purpose of this longitudinal study is to understand the relationship between an institution's engineering program rooted in active learning and undergraduate student persistence, particularly for women. Active learning pedagogy has been linked to retaining women.

Design/Method - At the beginning of their freshmen and sophomore years, students completed an adapted version of the Longitudinal Assessment of Engineering Self-Efficacy (LAESE) and the Student Responses to Instructional Practices Instrument (StRIP).

Results - Students reported higher levels of engagement and persistence than students at other institutions. These patterns were consistent for both men and women. Gender did not predict persistence to the beginning of sophomore year, even when controlling for differences in self-efficacy between women and men upon entering the program. Student engagement, as measured by StRIP, also did not predict persistence.

Conclusions - Utilizing an active learning pedagogy in an undergraduate engineering program may promote equitable persistence to sophomore year among women and men in an undergraduate engineering program.

Keywords: women, active learning, engineering, engagement, persistence, retention

Introduction

Historically, women have not been well-represented in the engineering profession. The percentage of women in U.S. undergraduate engineering programs is much less than 50%, with this percentage decreasing further by graduation. In 2009, 22.2% of undergraduate engineering students were women, and 17.8% of bachelors degrees were awarded to women [1]. In 2019, 23.8% of undergraduate engineering students were women, and 22.5% of bachelors degrees were awarded to women [2]. However, practicing engineers are only 11% women, with many female graduates choosing not to enter engineering and other female engineers leaving the field [3].

Given that it is critical to recruit and retain women in engineering programs, the purpose of this longitudinal study is to understand the relationship between an undergraduate institution's engineering program rooted in active learning and undergraduate student persistence, particularly for women. The literature review includes an overview of the research literature in active learning pedagogy in engineering, including short and long-terms outcomes of utilizing actively learning, followed by teaching methods characteristic of this approach. This literature is related to the pedagogical approach, teaching methods, and curriculum design that the faculty at the Loyola University Chicago undergraduate engineering program utilize.

Loyola University Chicago's Provost named Engineering a major initiative in the University 2015-20 strategic plan. Beginning in October, 2014, the Director of Engineering, with the supports of a campus-level Engineering Planning Group, started building this new program. As a former Bell Labs engineer, the Director used systems engineering [4] to plan a general engineering program that could meet the needs of industry [5-7], the engineering education community [8-16], engineering faculty [17, 18], and engineering students [19, 20] for at least two decades. In 2020, the program received ABET accreditation. In fall 2020, the Director and six faculty members taught 109 students across four classes and continue to focus on increasing the number of faculty members and students.

Loyola University Chicago's Bachelor of Science Engineering curriculum is a general engineering curriculum with three specializations. Students take common courses until the sixth semester, when they choose an engineering specialization: biomedical engineering (BME), computer engineering (CompE), or environmental engineering (EnvE). All Engineering courses are taught using mandatory active learning.Each specialization focuses on real-world applications, for example, high-quality medical devices for all patients (BME), sensors for the smart grid for energy efficiency (CompE), and wastewater treatment for water conservation (EnvE).

Literature Review

Active Learning Pedagogy

In contrast to passive lecture-oriented traditional education, active learning focuses on practical experience, interactive engagement, and students' motivation [21, 22]. Although there are several terms for active learning that may be used interchangeably, such as project or problem-based learning and collaborative learning, this review utilizes the term active learning to encompass this family of pedagogical approaches. A key strength of active learning is that students learn engineering concepts within a real-world context that results in deeper understanding and increased engagement. Short-term outcomes of active learning include increasing student engagement in class, improving students' examination results than traditional courses, and supporting more students to pass a course [23-25]. Long-term outcomes include shifting the focus from mathematics to the understanding of phenomena and conceptual thinking, increasing engagement and motivation to learn, and helping students gain self-confidence and a sense of accomplishment. Most notably, prior research has demonstrated that an active learning pedagogy retains female students and students of color [26-30].

Loyola University Chicago undergraduate Engineering program emulates parts of the U.S. Air Force Academy (USAFA) pedagogy on active learning, which is based on the Thayer method [31, 32] and Just-In-Time Teaching (JiTT) [33-37]. In most courses, the day before a course meeting, students take an online quiz to provide instructor feedback as to which homework topics should be emphasized during the first 10-15 minutes of a 50 minute course meeting. In all courses, this mini-lecture is immediately followed by one or more activities that promote active learning, such as collaborative learning, design exercises, lab measurements, or case studies. Each course section holds no more than 24 students to facilitate active learning. In the remainder of the literature review, descriptions of the different elements in active learning are provided: peer instruction, design exercises, and social justice case studies.

Peer Instruction. Peer instruction is another method to enhance students' conceptual understanding. The critical components of peer instruction are the questions ought to be discussable and small group conversation is held so that every students' voice could be heard [24]. Questions and conversations help students to identify incorrect understanding and gaps in their knowledge, so that their conceptual understanding improves. During the process, students are active and engaged in interaction. In most Loyola University Chicago Engineering courses, students spend the majority of classroom time in small groups of 3 to 4 students, working on an assigned problem. Moveable whiteboards enable each group to be separated from the other groups, with each group member contributing towards the solution. The instructor moves between the groups, eliciting problem assumptions and guiding students towards the direction of a solution.

Design Exercises. With taught knowledge, students are asked to apply the knowledge to find a satisfactory solution to a problem. The types of exercises used are critical to develop this method. The exercise should not have only one strictly defined solution, so that students are encouraged to integrate their ideas and collaborate. Besides, the exercises cannot be divided into separate parts, to prevent each team member from working individually [38]. Long-term assessment increase students' engagement in the learning process and working continuous naturally improves the learning result [39]. Hard work is also crucial, because it gives resources to students to win difficulties and express insights. Students improve self-confidence, gain a sense of accomplishment and learn to cooperate with each other [40]. Also, a common method in science courses is lab measurements. By practical measurement, such as measuring, doing calculations, and conducting simulation, students not only get familiarized with laboratory equipment, but also connect theory to practice [25]. This practice may strengthen students' professional skill by making students focus on understanding the phenomena.

The Loyola University Chicago Engineering curriculum incorporates an open-ended design project during the first semester [11] and a two-semester senior capstone project sponsored by industry. Three multi-phase design activities related to each specialization are also being integrated throughout the curriculum, in addition to the routine active learning activities. Because these activities are intentionally integrated across the four-year program, yet also interconnected, the program refers to them as contextual threads. Each contextual thread is introduced during the freshman design course (ENGR 101) and expanded during the sophomore and junior years. A contextual thread enables students to learn engineering concepts within a real-world context.

For example, students are introduced to patient monitoring through a cardiograph project in the freshman design course. A cardiograph is a medical instrument that accurately acquires and displays a patient's electrocardiogram (ECG). Obtained from the surface of the skin, an ECG is the summation of cardiac currents, used to diagnose abnormal cardiac rhythms. The cardiograph project is an expansion of two lab experiments in the Director's medical device textbook [41]. Over three years, each student builds a functional cardiograph (specifically for educational use only, which is exempt from Institutional Review Board approval), which she will own after junior year.

Social Justice Case Studies. Engineering case studies sensitize students to experiences outside of the classroom [42-44] and increase critical thinking and engagement [45, 46]. Case studies provide a means for students to understand historical, economic, social and political contexts that shape engineers, the engineering profession, and the practices of engineers. Studies have demonstrated cases promote meaning in learning engineering content, and encourage student participation and persistence [47, 48]. Case studies also provide opportunities for students to engage with and practice ethical decision-making in relation to the engineering profession [49].

At Loyola University Chicago, the combination of engineering and social justice is not a "controversial topic," as it is at so many universities [50, 51] but is an extension of business-as-usual. Social justice should not be invisible in engineering education and practice [52]. Faculty provide social justice examples from all three specializations throughout the curriculum.

In addition, faculty embed four social justice case study projects in four semesters of the curriculum: ENGR 101: Introduction to Freshman Design, ENGR 201: Experiential Engineering, ENGR 321: Electronic Circuits & Devices, and ENGR 381/382/383: Specialty Capstone Design I. The case study format varies each semester. Freshmen groups are introduced to the case study approach in ENGR 101, when each group reviews assigned documents of a case, and then later describes the case to other groups during a reserved course meeting. These sets of case studies were and continue to be designed by the Director, who previously created a textbook of engineering ethics case studies [53]. The U.S. Senate Hearing Panel case study implementation is fully described in her textbook [54] as an Ethics Laboratory. Project outputs from three of the four case study projects are used as evidence for continuous improvement of ABET Student Outcomes (3) and (4), which cover to effective communication and ethical and professional responsibility, respectively.

Given the research on the impact of active learning teaching methods and the innovative curricular design of the undergraduate Engineering program at Loyola University Chicago, the research questions for this study include the following:

- What are the characteristics of students that persist in the Loyola University Chicago Engineering program from the Class of 2022 and 2023?
- To what extent and in what ways does a curricular emphasis on active learning promote student engagement and persistence among engineering students, particularly women?

Based on the research literature, we hypothesized that students enrolled in the Loyola University Chicago engineering program would have a higher level of persistence than students in other Engineering programs. Also, we hypothesized that engagement would be more critical for women than men for persisting in the Engineering program.

Design

Participants

Eighty-eight students, across two cohorts—graduating classes of 2022 and 2023--were eligible for a study during their Freshmen and Sophomore years in the Loyola University Chicago Engineering program (see Table 1 for sample and retention details). Survey response rates were high, suggesting a representative sample. Although survey response rates were similar across classes, rates of persistence were different. Since only 18 students dropped out of engineering and participated in some data collection, separate analyses for students that dropped out of the program were not reported as part of this study.

Table 1: Sample, Response Rate, and Retention

	Class of 2022		Class of 2023	
	N	%	N	%
Incoming Freshman	39	NA	49	NA
Completed Freshman Survey	31	79%	37	76%
Students Persisted to Sophomore Year	21	54%	41	84%
Completed Sophomore Survey	16	43%	28	72%
Completed Both Surveys	15	38%	25	51%

Data Collection

Students completed an online survey at the beginning of both their Freshmen and Sophomore years. This survey was an adapted version of an annual Assessing Women and Men in Engineering (AWE) [55] and also integrated the Student Response to Instructional Practices (StRIP) Instrument [56]. Questions on the AWE included demographic information, measures of self-efficacy (only for Freshmen administration), and reasons for choosing and persisting in Engineering (only for Sophomore administration). These items were used to track factors that are related to persistence from previous research to provide control variables. The StRIP Instrument includes the constructs of value, positivity, participation, and distraction to measure the extent to which students are cognitively, affectively, and behaviorally invested in a class. The StRIP was administered with the Freshmen and Sophomore survey.

A research team member outside of the Engineering program administered the online surveys during ENGR 101 and 201 within the first three weeks of class. Class of 2022 completed the surveys in fall 2018 and fall 2019, and the class of 2023 completed the surveys in fall 2019 and fall 2020.

Analysis

Descriptive and inferential statistics demonstrated minimal differences between the two cohorts on the data collection tools used in the study, except for persistence. Analysis between cohorts 2022 and 2023 revealed a significant association between cohort and persistence, $^2(1) =$ $\chi^2 p = 0.02(1) = 5.438$, $p = 0.02$. Program faculty attributed the difference in persistence between the cohorts to the cohesion among students, which is stronger for class of 2023 than class of 2022. Related survey items (e.g. I can relate to the people around me in my classes.) were not significantly different between these cohorts, although a measure of social cohesion or belonging was not included in the original study design. Given differences were only evident with persistence, all remaining analyses combined the two classes, and class was a control variable in further analyses.

For the first question, comparisons were made between students who remained and left Engineering by their Sophomore year on the survey taken at the beginning of their Freshmen year using independent samples t-tests. For the second question, comparisons in scores were made between Freshmen and Sophomore years for all students that remained in the program, in addition to comparing the experiences of men and women that persisted in the program using independent samples t-tests. Finally, a logistic regression model was developed to analyse predictors of persistence in Freshmen.

Results

Students that identified as women persisted at similar rates as men, 76.6% (n = 36) and 72.9% (n = 43), respectively. Chi-square analysis demonstrated that gender and persistence were not related. These rates are slightly lower than Loyola University Chicago's average retention rate for sophomores, which is about 85%. Although it was not possible to track systematically students that did not persist in the Loyola University Chicago Engineering program, several of these students remained enrolled at Loyola University Chicago and switched majors, such as to Computer Science or Pre-Med with major in Biology.

Like gender, analysis by race revealed no statistical differences in relation to persistence. However, descriptive data for race points to a need for further research. Among the small sample of students who identified as African American (n = 1), Latino/Hispanic (n = 5), Asian and Pacific American (n = 13), Multi-racial (n = 12), or another race/ethnicity (n = 5), trends suggest that rates of persistence may be lower for Latino/Hispanic Americans (40%) and Asian and Pacific Americans (61.5%) than Caucasian (71.9%, n = 32). Black or African American and Multi-racial groups had too few participants to report these findings. The remainder of the analyses focused on gender.

Similar rates of persistence existed for women and men, even though when they began the program there were statistically significant difference between mean scale scores for freshmen women and men on some measures of self-efficacy. For the Self-Efficacy Scale II, $t(66) = 2.63$, $p = .011$; Career Success Scale, $t(66) = 3.03$, $p = .004$, and Math Scale $t(66) = 2.49$, $p = .015$, men averaged higher scores than women (see Table 2 for averages). Although men scored higher than women on the Self-Efficacy I Scale and Coping Self-Efficacy Scale, these results were not significantly different. Women and men scored similarly on the Inclusion Scale. The means on self-efficacy scales at the beginning of Freshmen year were also compared between students that persisted into their Sophomore year with those that did not (see Table 3). Although means were generally slightly higher for those that persisted than those that did not, there were no statistically significant differences in the mean Freshmen scale scores between those who persisted and those who did not.

Table 2: Self-Efficacy Scale Averages for Freshmen Women and Men from Cohorts 2022 and 2023 in the Loyola University Chicago Undergraduate Engineering program.

	Men (41)		Women (27)	
	Mean	Std. Dev.	Mean	Std. Dev.
Coping Self-efficacy Scale	34.90	4.50	32.85	6.53
Self-efficacy I Scale	28.71	6.61	27.78	4.25
Self-efficacy II Scale *	30.46	3.26	27.89	4.83
Career Success Scale *	40.00	5.88	37.26	6.94
Inclusion Scale	20.46	4.95	20.46	4.83
Math Scale*	17.80	2.96	15.78	3.72

**Statistically significant at = 0.05*

To further explore how gender might relate to students' persistence, among the students that persisted to their Sophomore year, we compared subscale scores of women and men on the StRIP instrument using and independent means t-test. There were no statistically significant differences between the mean subscale scores for women and men in both freshmen and sophomore years. Nor were there differences between mean scores for students who persisted and those who did not. However, a paired means t-test found a statistically significant difference, $t(39) = -2.136$, $p = .039$, between the StRIP Explanation Subscale scores of freshmen and sophomore students (see Table 4). On average, sophomores rated instructor explanation higher (M = 4.26, SD = .60) than freshmen (M = 4.01, SD = .66).

Table 3: Self-Efficacy Scale Averages for Freshmen from Cohorts 2022 and 2023 in the Loyola University Chicago Undergraduate Engineering program that Persisted and Did Not Persist to their Sophomore Year.

	Persist (50)		Do Not Persist (18)	
	Mean	Std. Dev.	Mean	Std. Dev.
Coping Self-efficacy Scale	33.96	5.40	34.44	5.71
Self-efficacy I Scale	28.86	5.26	26.89	6.96
Self-efficacy II Scale	29.66	4.15	28.33	4.11
Career Success Scale	40.42	6.96	39.28	5.98
Inclusion Scale	20.56	5.03	20.18	4.45
Math Scale	17.06	3.33	16.83	3.71

There was no statistical difference between the means of students who do persist in year 1 and those that do not.

Table 4: StRIP Subscale Paired Sample t-test for Cohorts 2022 and 2023 in the [Instituion] Undergraduate Engineering program.			
	N = 40		
	Year	Mean	Std. Dev.
Distract	Year 1 Year 2	1.71 1.66	.49 .51
Explanation*	Year 1 Year 2	4.01 4.26	.65 .60
Facilitation	Year 1 Year 2	4.12 4.24	.71 .65
Participation	Year 1 Year 2	4.53 4.52	.53 .53
Positivity	Year 1 Year 2	4.22 4.24	.49 .53
Value	Year 1 Year 2	4.14 4.15	.66 .52
**Significant at p = 0.039.*			

Finally, a logistic regression was conducted in attempt to identify predictors of persistence. First, a simple logistic regression was conducted with all variables of interest including the Self- Efficacy Scales, StRIP subscales, *1.286*, *SE* = gender, and cohort. Significance was found only when persistence was regressed on cohort*(β)* = 3.619, , = 0.024β = *1.286, SE* = 0.569, *Wald* = 5.107, *Exp(β)* = 3.619, *p* = 0.024. Thus, a student from cohort 2023 is 3.619 times more likely to persist than a student from cohort 2022. The final model included all StRIP subscales. gender, and cohort as the control variable. However, none of the variables significantly predicted persistence in the multiple logistic regression model, and cohort ceased to be a significant predictor.

Discussion

The findings from this study support prior research findings that have demonstrated the value of active learning pedagogy in undergraduate engineering programs [24-26, 57]. Most notably, active learning pedagogy may be a means to promote persistence among women during the first year of their engineering program. Engaging students in active learning at the start of an engineering program seems to be a valuable mean to support persistence, rather than waiting for such approaches for senior design projects and other advanced courses. Students reported high levels of engagement in their learning during their freshmen year based on the StRIP tool, which were also high scores in comparison to the samples reported when the tool was developed [56].

Women stayed in Engineering at similar rates as men, even though they began the program with lower levels of self-efficacy. These findings on gender are atypical because gender is often a factor for persistence in other Engineering programs [20, 27, 29] . However, gender does not seem to impact the persistence of the freshmen and sophomores in this study. Assuming the retention rates at the beginning of Sophomore year do not substantially change by the time of graduation, the Loyola University Chicago undergraduate program will continue to graduate approximately 50% women. Now that it is ABET-accredited, the program can participate in annual ASEE surveys and is on track to rank in the ASEE Top Schools Offering Bachelor's Degrees to Womenin 2021. While undergraduate engineering programs typically graduate approximately 20% women, the Loyola University Chicago program has graduated approximately 50% women in its three initial classes. In 2019,the University of North Carolina at Chapel Hill was ranked 10th Top School, with 44.2% [2].

Active learning pedagogy also continues to retain men. Thus, active learning pedagogy may be considered a pedagogical approach that promotes universal design in engineering curriculum. That said, descriptive data suggests a potential differential impact based on racial groups. However, this paper's small racial subsamples limit this analysis. Follow-up research ought to explore the experiences and mechanism of change for students of color. A universal approach to curriculum ought to support all learners. Prior research has demonstrated that active learning benefits both women and students of color [26, 27, 29, 30]. The small number of students of color in this sample were representative of those in the program. Having a small number of students of color in a predominately white program can contribute to lower retention rates of students of color.

Limitations

This study has several limitations, which also suggest other areas for future research. First, it is important to note that although we observed a strong, possible association between the engagement in active learning and high persistence rates for men and women, this study design does not provide a means to make a causal link between them, nor a means to understand the mechanism of change associated with the relationship between active learning and retention. Also, students' engagement, as measured by StRIP, did not predict retention, but that may also be due to limited variability on student engagement in this sample. To address these concerns, future research ought to incorporate a mixed methods design with qualitative findings to explore the link between active learning and persistence. Alternatively, or in addition to, a study with a comparison group from a university that does not integrate an active learning pedagogy or a sample with greater variability with active learning. The challenge of such a study is that there is likely several mechanisms of change associated with retention to consider and potentially control in relation to active learning. In addition to the problem-based and collaborative approaches in the classroom, the Loyola University Chicago program has small class sizes that facilitate strong relationships between students and faculty, and integrates frequent, rapid assessment. Although student belonging was not addressed in this study, it may be critical for the mechanism of change in this program, given the differences. This program also has specializations in biomedical and environmental engineering, which tend to attract more females than other specialties.

Finally, this study focused on retaining students through their Freshmen year of college when students are most likely to leave engineering. During the Freshmen year, students at Loyola University Chicago have only one Engineering course, and the other courses in math, science, and liberal arts core may not have utilized actively learning pedagogy. For this reason, it is also important to track student experiences through their entire undergraduate experience since active learning intensifies in advance courses and senior design projects.

Conclusion

Retaining women in engineering programs is critical for supporting a pipeline of future engineers to solve problems relevant to what people encounter in their daily lives. This study adds to the literature that has demonstrated the value of active learning by characterizing active learning pedagogy in the Loyola University Chicago undergraduate engineering program that the freshmen experience. The Loyola University Chicago program provides a potential model to other engineering programs looking to improve their retention of women.

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