Increasing Graduate School Enrollment of Female Industrial Engineers through CUREs

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Abstract – Work In Progress

This is a Work in Progress paper. Decades after recognizing the need for more women engineers, increasing the number of women enrolling in engineering graduate schools still remains a challenge. From ASEE data published for 2017, record percentages of engineering degrees were awarded to women for Bachelors, Masters, and PhDs at 21.3%, 25.7%, and 23.5% respectively. Per the US Census Bureau, women comprise 50.8% of the American population; therefore, we must ask, "why aren't 50% of engineering degrees awarded to women?" Within the industrial, manufacturing, and systems engineering professions, a higher percentage of women earn degrees (32.7% BS; 25.5% MS; 26.6% PhD) than for all engineering disciplines combined, but these numbers still don't approach 50% of the population. To increase the percentage of female industrial engineers pursuing graduate school in the Industrial and Manufacturing Systems Engineering department at Iowa State University, we have implemented a Course-Based Undergraduate Research Experience (CURE) into a second-year human factors course. It is hypothesized that having this experience will encourage more women to continue their industrial engineering education beyond their bachelor's degrees. A preliminary trial was run in the Spring 2018 semester, and a follow-up trial is being run in the Spring 2019 semester. Eighty-nine students (male and female) who experience the CURE pedagogy will be tracked longitudinally and compared to students who learn the same material through traditional lecture pedagogy. This paper describes the process, initial results from the Spring 2018 semester, and changes for the Spring 2019 semester, along with lessons learned about using a CURE pedagogy, measuring retention, and tracking graduate enrollments.

Introduction

ASEE data from 2008-2017 shows that while the percentage of women in engineering has increased slightly over the past ten years, it is virtually unchanged at 21.3%, as can be seen in Figure 1 [1]. This same conclusion is supported by other sources, including Lichtenstein et al using National Science Foundation data [2]. Compared to the overall US population of 50.8% women [3], there is significant room for improvement, with improvement defined as an increase in this percentage. Those in the engineering professions know, and have known for decades, that this percentage needs to increase, yet society struggles to make any noticeable improvement.

While "engineering" as a discipline is commonly discussed in literature, almost no research specific to industrial engineering retention and graduate school was identified. The only research found addressing industrial engineering student retention and graduate school enrollment includes papers published by the authors of this paper as their work in this area has progressed [4, 5]. Industrial engineering has traditionally had one of the higher percentages of undergraduate women of all engineering professions, but it has increased only slightly from 2009 until 2017, from 30.2% to 32.2% respectively [1].

Iowa State University (ISU) is a large, land-grant institution located in rural Iowa. Data from ASEE online college profiles for 2018 show that ISU has a total undergraduate enrollment of

29,621 students, and a total graduate enrollment of 4,774 students [6]. Of these undergraduate students, the Industrial and Manufacturing Systems Engineering (IMSE) department reported 471 full-time students for 2018: 73.2% white and 26.8% black, Asian, American Indian, Hispanic, Pacific Islander, unknown, nonresident alien, and two or more ethnicities [6]. ISU's IMSE department's self-reported data to ASEE for degrees awarded to female students at the BS, MS, and PhD levels are shown in Figure 2 [6].

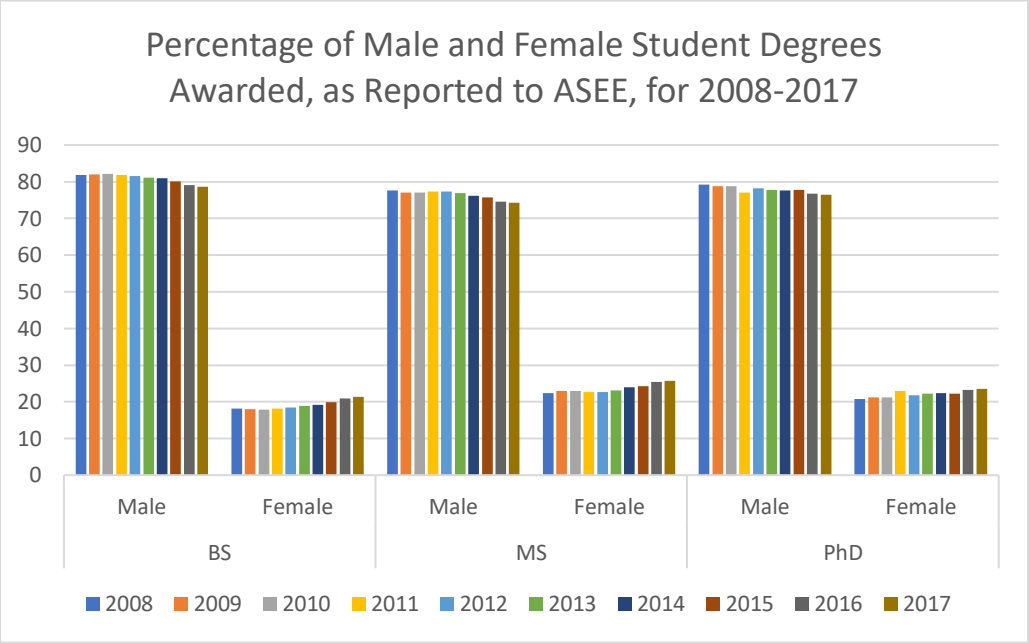

Figure 1: ASEE data of percentages of degrees awarded by gender from 2008-2017 [1]

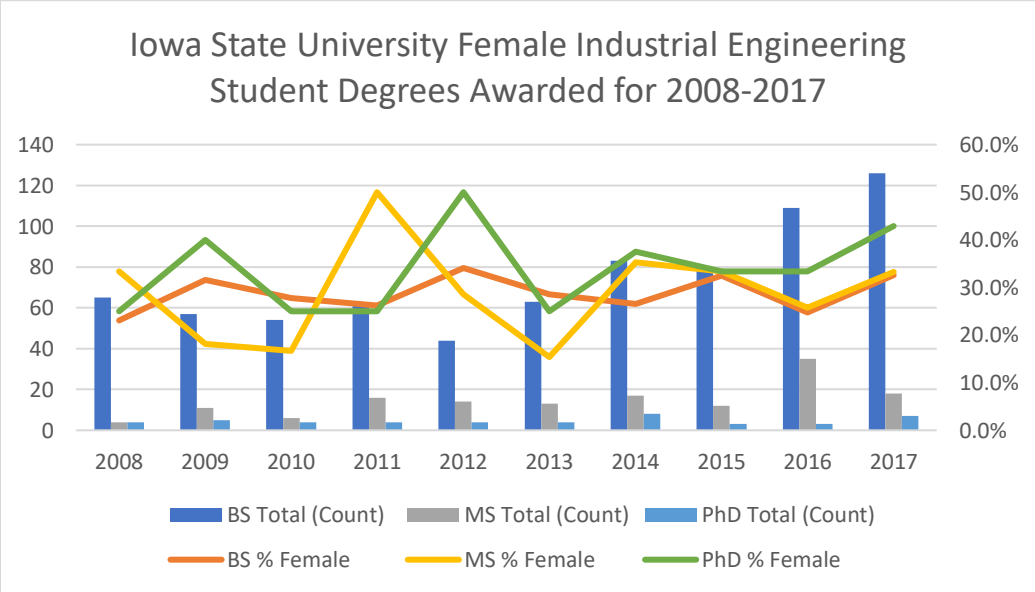

Figure 2: Iowa State University degrees awarded to female industrial engineering students from 2008-2017, with counts on the left-hand Y axis, and percentages on the right-hand Y axis [6]

None of the trendlines for percentages in Figure 2 have a high enough R-squared value to say that there is a predictable trend; the largest R-squared value is less than 0.3. For this reason, trendlines were not plotted. Over the ten-year time frame, the percentage of BS degrees awarded to women by ISU's IMSE department vacillated between 23-34%. The percentage of MS degrees awarded to females ranged between 15-50%, and the percentage of PhD degrees awarded to females ranged between 25-50% [6]. The good news is that from a percentage viewpoint, some years the department is hitting the 50% mark, close to the general US population. However, the overall numbers of students enrolling in graduate school is very small and the average enrollment is significantly below 50%. Both issues must be addressed.

Therefore, the question is how to increase the number of female industrial engineering students enrolling in graduate school, in terms of count and percentage of the graduate population? Anderson-Rowland describes the four steps that a student must go through to "make it to" graduate school. They include 1) *considering* graduate school, 2) *choosing* to go to engineering graduate school instead of MBA, law, medical, or other non-STEM graduate school programs; 3) *applying* to graduate school; and 4) *enrolling* in graduate school [7]. Step 0, which isn't listed but perhaps should be added, is 0) *remain* in the major through their undergraduate program (retention).

There are many different theories, techniques, methods, and pedagogies being actively studied to assess their impact on the percentage of women remaining and persisting in STEM fields. One of these is Course-Based Undergraduate Research Experience (CURE). Extensive research is found in the literature supporting the benefits of a CURE pedagogy, including its positive influence on STEM retention and progression to graduate school [8] – [13]. For example, according to Harris et al., students' interest in pursuing scientific studies may increase because of research experiences [9]. Mendoza and Brown discuss that CUREs are well-documented, and that it is generally agreed that they are positive experiences for students [13]. They also note that research experiences are considered high impact and lead to student success, engagement, interest in higher education and skills development [13]. Many citations from the growing body of research which documents student benefits gained from undergraduate research are noted by Auchincloss et al., including that research experiences "are thought to be especially beneficial for women and underrepresented minority students, presumably because they support the development of relationships with more senior scientists and with peers who can offer critical support to students who might otherwise leave the sciences" [10].

Lopatto noted that while some research findings have shown significant increases in graduate studies interest as a result of undergraduate research, others have shown no increased interest [8]. Lopatto also notes that the relationships between "who," "what," and "when" are complex; for example, older students who might be pre-disposed to like research might purposely pursue it [11]. For this reason, it might be worth offering research opportunities to younger students; as of his report in 2010, the effectiveness of this tactic in increasing the number of students who continue to choose to study the sciences was unknown [11]. Current literature has shown that both women and minority students stay in their chosen field at a higher rate (retention) and that students apply to graduate school at a higher rate (persistence) when they have experienced hands-on undergraduate research experiences [2]. It is noted again that no research besides that

related to the authors of this paper could be found which discusses the impact of CUREs on the female industrial engineering population.

For these reasons, since 2013, a strong emphasis of the IMSE department at ISU has been undergraduate research. Students who apply for and are accepted by faculty for research projects each semester are funded by the department. This program has grown since 2013, and now includes 10-20 assistantships/semester. As reported at the 2018 Institute for Industrial and Systems Engineers Conference, ISU's IMSE department has had excellent success with students who have had undergraduate research experiences continuing to graduate school [14]. Similarly positive, the number of students who had not considered graduate school before their undergraduate research experience, and then afterwards changed, were reported as changing from 6 to 1 and 7 to 5 for F'16 and S'17, respectively [14].

There appears to be general consensus in the literature that a CURE pedagogy leads to positively influencing students about their choice of major, thereby possibly increasing retention. There is also an expectation that it encourages more female students to enroll in graduate school. The authors' specific findings indicate a positive impact of research experiences on graduate enrollment. Given these findings, the following research questions were formed with respect to the industrial engineering major:

1. Does having a CURE experience inspire more female industrial engineering students to stay in the major?
2. Does having a CURE experience inspire more female industrial engineer students to consider/apply to graduate school?

This paper is organized as follows: the methods for this research are described, followed by results and discussion. The primary focus of this paper includes the preliminary data that was collected, and how the methods were modified for the second trial of the CURE pedagogy. Changes in the methods from Spring 2018 to Spring 2019 offerings of the course are included. Lessons learned are also identified. Finally, conclusions are offered, including a discussion of the limitations of this undertaking, as well as next steps.

Methods

Prior to the Spring '18 semester, grant money and departmental assistance were secured to fund supplies and undergraduate research assistants to help with implementing a CURE pedagogy. Institutional review board approval for the study was initiated; approval was granted prior to data collection in the courses. A trial CURE was implemented into IE271 by Dr. Richard Stone in collaboration with Ms. Leslie Potter (both IMSE faculty) and with Devna Popejoy-Sheriff (IMSE advisor) in the Spring 2018 semester. IE271 is a second-year human factors and ergonomics course with an enrollment of approximately 120-130 students/year in two combined sections. IMSE's Spring 2018 section had 40 students enrolled. Students in the CURE section learned the same material as the traditional section, but the pedagogy was revised from traditional lecture to hands-on research in four different modules, which are explained in detail in a previous paper [14]. The research experiences were based on Lopatto's criteria for "good research projects": reasonable scope, feasible, generate data that students can present, not "cookbook" experiments,

built-in difficulties, and multifaceted [8]. For the Spring 2018 semester, the CURE was implemented as four different manufacturing and service laboratory-type exercises and one group project.

Preliminary results were collected in the form of pre- and post-surveys from the students. During the third week of class, after which there were no drops or changes in enrollment, students were informed about their option to voluntarily participate in the data collection process. Two paper surveys were used: one in week 4 and one in week 15 of the semester. No reward of any kind was offered; participation was completely voluntary and without incentive. The only restriction was that students had to be eighteen years old or older, and none of the students in the two sections were younger than eighteen years old. Examples of the types of survey questions posed to students are included in Table 1. The allowable responses varied for the different questions, but for most required students to supply an answer on a spectrum similar to a Likert scale, ranging from one extreme to another. An example of the allowable responses for given questions can be seen in Tables 4-8. For the Spring 2018 semester, twenty-seven students completed both the pre- and post-surveys, including 13 control and 14 treatment students. Students took the survey during class and returned it to one of the PIs who was not an instructor.

Table 1: Types of questions asked on pre- and post-survey

1. Have you participated in academic research prior to taking this course?
2. How "set" are you on your current major?
3. Do you have goals/plans to continue your education beyond your undergraduate degree?
4. What will you most likely do immediately following graduation?
5. Before I started this research experience…
6. After having the experience of my research project in this class…
7. I enjoyed the responsibility
8. I gained self-confidence
9. I felt unprepared
10. My oral communication skills improved
11. I liked the hands-on research
12. I prefer traditional lectures to hands-on learning
13. Research made the course work more interesting
14. I learned more from the course work than the research
15. Research made me like industrial engineering more
16. Clarification of career path
17. Tolerance for obstacles faced in the research process
18. Understanding of the research process in IE
19. Ability to integrate theory and practice
20. Understanding of how to work on real problems
21. Learning how to work independently
22. Learning how to work in teams
23. Becoming part of a learning community
24. Confidence in my potential to be a teacher of engineering
25. Evaluate your overall sense of satisfaction

While the data collected during the first trial was insufficient in quantity for statistical analysis or significance testing, it was very promising anecdotally. Student responses for the different survey questions were tallied. The only comparison that can be made across the sections will be completed longitudinally as the numbers of students changing majors and the number of students continuing to graduate school over the next three years are recorded. Within the treatment (CURE) section, changes in student attitudes and opinions were observed. Based on the promising results of this initial data collection, it was determined that a second trial semester of including a CURE was warranted.

To execute a second trial, new funding for undergraduate teaching/research assistants and supplies had to be obtained. Because of the grant received to support this endeavor, laboratory and project content had to be modified to focus the course on NASA and space-related work environments. New laboratory experiences were developed which maintain the same research requirements, but emphasize different topics and applications within human factors and ergonomics. The first lab addresses manual material handling, including but not limited to space station items. The second lab addresses time study, line balancing, and PERT, as students create and optimize the flow of small rockets. The third and fourth labs are conducted in a swimming pool and focus on environmental engineering and tool engineering. Students work in a near zero setting in a real-world simulation of the International Space Station. The group project is based on optimizing space flight operations.

For the Spring 2019 semester, there are currently 96 students in the control section, and 49 students in the treatment section. Enrollment was not managed in any way; students enrolled in whichever section fit into their schedules. Surveys were distributed and collected in weeks 4 and 15 of the semester. With new IRB approval, the surveys were conducted electronically rather than on paper, with the goal of increasing response rates.

Results and Discussion

Data for the Spring 2018 semester are reported in Tables 2-8. Table 2 includes basic demographic (male vs. female) enrollment numbers for both Spring 2018 and Spring 2019 semesters.

Table 2: Basic demographics of students taking IE271 (*not all students responded to gender question)

	Treatment	# Students			
Semester	Section Type	Total Students	Total Respondents	Female Respondents	Male Respondents
Spring ‘18	Control	92	13	7	6
	Treatment	40	20	12	8
Spring ‘19	Control	96	31*	11	17
	Treatment	49	47*	11	33

For Spring 2018 data, the majority of respondents self-reported as 2nd year students in the industrial engineering curriculum (20 of 33, or 60.6%). We note that one student from the treatment section self-reported as a mechanical engineering student who had not fully committed

to his major yet. Students also self-reported their ethnicities, but that data is not included in this analysis. For this analysis, only responses returned by female students is included, which totaled twelve students for the Spring 2018 treatment section.

Students responded to a variety of questions about their prior research experience, previous considerations regarding graduate school, etc., examples of which were shown previously in Table 1. All questions were answered using different Likert scale and predefined options, though response options varied between sets of questions. Table 3 shows the number of students in each section who reported having a prior research experience. The type of experience wasn't specified (e.g., REU vs. CURE vs. undergraduate research assistantship (URA)).

Table 3: Spring 2018 responses (yes/no) to whether or not a student has had prior research experience (*reporting only female student responses)

Survey Question	Section Type	# Students*	
		Yes	No
Have you participated in academic research prior to taking this course?	Control	0	7
	Treatment	3	9

Of the three students in the treatment group who reported previous research experience, one changed her opinion about the major (from feeling strongly to very strongly), but this didn't change her plans to pursue a non-IE graduate degree. The other two students who had previous research experience didn't change their opinion about the major as a result of the CURE experience.

While most of the survey questions were tailored for students in the CURE section with "before" and "after" statements, both the control and treatment sections were asked "How set are you on your major?" Responses from female students to this question are shown in Table 4.

Table 4: Spring 2018 student responses to "How set are you are your current major?"

# Female respondents for response options listed below:	Control		Treatment	
	Pre	Post	Pre	Post
Very strongly – no doubts	1	3	5	7
Strongly – but still trying to figure out which focus area suits me best	6	4	6	5
Pretty confidently – but sort of still looking around	0	0	1	0
Not very sure about it – definitely looking at other majors	0	0	0	0
I have already decided that I need to change my major	0	0	0	0
Prefer not to answer	0	0	0	0

The interesting point about Table 4 is that the total number of students who reported being very strongly convinced about industrial engineering as a major increased for both the treatment group (5 to 7), and for the control group (1 to 3). Similar results are seen for the treatment-only respondents regarding the question "Before I started this research…" and "After I completed this research…" as shown in Table 5. One respondent changed their answer to say that they were sure they wanted to be an industrial engineer (IE) after the research experience. What is unknown is if the CURE experience contributed to the move toward higher confidence in the major choice for the treatment group, as well as what might have caused the move in the control group.

Table 5: Spring 2018 student responses to "Before I started/After I completed this research…"

# Female respondents for response options listed below:	Treatment	
	Before	After
I was sure that I wanted to be an IE	11	
I was unsure that I wanted to be an IE	1	
I am still sure that I want to be an IE		12
I am questioning my choice of major but will continue for now		0
I have decided to change my major		0
Prefer not to answer		0

In Table 6, responses to "Before having this research experience…" and "After having this research experience…" are shown for the female students from the treatment section. This data is inconclusive, as the only movement is from "I planned not to pursue post-undergraduate education" to "Prefer not to answer."

Table 6: Spring 2018 student responses to "Before/After having the research experience in this class…"

# Female respondents for response options listed below:	Treatment	
	Before	After
I had not considered options for post-undergraduate education	2	2
I planned not to pursue post-undergraduate education	3	2
I had plans to pursue a Masters degree in an engineering related field	1	1
I had plans to pursue a PhD in an engineering related field	0	0
I had plans to pursue a Masters degree in a non-engineering related field	4	4
I had plans to pursue a PHD in a non-engineering related field	0	0
I had plans to pursue a medical degree	0	0
I had plans to pursue a law or other professional degree	1	1
Prefer not to answer	1	2

Selected results from the treatment group about preferences and opinions regarding research are shown in Table 7. In these responses, one of the twelve students chose all "Not applicable" responses, so the dataset is effectively reduced to eleven. There are some interesting results, in that research is not unanimously appreciated or liked. While six students said they strongly disagree with the statement, "I prefer traditional lectures to hands-on learning," two said that

they agree with that statement. Students were consistent with their likes and dislikes, validating those responses several times. While seven responses were "Agree" or "Strongly Agree" for "I like hands-on research," three students said they disagreed that research made them like industrial engineering more.

Table 7: Spring 2018 student responses to "Before/After having the research experience in this class…"

# Respondents Post-CURE for statements listed below:	Likert Scale Response Options					
	Strongly disagree	Disagree	Neutral	Agree	Strongly Agree	Not Applicable
I prefer traditional lectures to hands-on learning	2	4	3	2	0	1
I liked the hands-on research	0	1	3	5	2	1
Research made the course work more interesting	0	2	1	5	3	1
I learned more from the course work than the research	1	3	4	2	1	1
Research made me like industrial engineering more	0	3	2	4	2	1

Two of the twelve students responded that they had a "large gain" in the clarification of their career path. While it isn't possible to sort out what that means to the student or what they might have decided as a result, it is encouraging that a class can provide clarity, regardless of whether that is to remain in the major or to pursue something different. When considering Table 8 responses in conjunction with Table 4 responses, which shows that all twelve female respondents are either "Strongly" or "Very strongly" set on their major post-treatment, this clarity can be presumed to be within the field of industrial engineering as opposed to causing a student to change professions.

The last question included in Table 8, "Confidence in my potential to be a teacher of engineering," indicates that the majority of students felt they had a gain in this area, and for two students, a large gain. Being able to teach others and having the confidence to do so indicates that students are grasping the material enough to take risks in mentoring others. This is one of the attributes that CURE research considers positive and something that helps students feel connected to their profession and peers, which is believed to positively affect retention.

Table 8: Spring 2018 student responses regarding career path and teaching engineering

# Respondents Post-CURE for statements listed below:	Likert Scale Response Options					
	No gain or small gain	Small gain	Moderate gain	Large gain	Very large gain	NA/Prefer not to answer
Clarification of career path	1	5	2	2	0	2
Confidence in my potential to be a teacher of engineering	3	3	3	2	0	1

Finally, while no table summary is necessary, it is important to note that one of the twelve female respondents from the treatment group changed her indication about post BS plans after her CURE. On her pre-survey, she indicated that she felt very strongly about industrial engineering as a major and had no doubts, and that she planned to go straight to industry with no graduate school after earning her BS. On her post-survey, she still felt very strongly about the major, but changed her post BS plans to "Work first, then get MD, PhD, or professional degree." If one out of every twelve female students in industrial engineering could be persuaded to enroll in a PhD program, and if all students in ISU's IMSE department had a CURE in their IE271 course, it could perhaps mean an additional three female graduate students/year.

Lessons Learned

Lessons learned from this research undertaking include the following:

1. Implementing a CURE pedagogy is no small undertaking. It requires resources: funding for teaching/research assistants, funding for expendable supplies, faculty time to develop, faculty time to execute, and faculty and staff time to assess.
2. Making surveys easy to complete might increase the return rate – for the Spring 2019 semester electronic surveys were used rather than paper surveys.
3. Asking students to explain answers would allow better understanding of their responses.
4. Putting a plan in place for measuring persistence (continuation to graduate school) is necessary to ensure that data is captured despite personnel and process changes within a department and university.
5. Measuring retention is best done within the purview of the department.
6. Small gains, while not necessarily significant, are still real and make a tremendous difference for individual students.

Conclusions

Data collected during the Spring 2018 semester initial CURE trial indicated both interesting and some positive anecdotal results. While the number of respondents wasn't high enough for data analysis of significance, it was encouraging enough to support collecting data for a second semester. Because of the grant funding stream secured to support a second semester of CURE implementation in IMSE's IE271 course at ISU, an additional 49 students are currently taking the course with a CURE component. Pre-CURE data was collected, post-CURE data will also be collected and added to the existing data, and comparisons of control and treatment students will be completed. The goal is to determine if having a CURE experience is correlated with inspiring more female industrial engineering students to stay in the major, and to determine if more of the same population consider/apply to graduate school.

Limitations of this work are many, the biggest of which is that while some insight is gained into student decisions, feelings, and preferences about their major and educational goals, this study doesn't parse out the data at a level which will allow causation to be definitively determined; only correlation will result from this study. A second limitation from the initial trial is in the low response rates; the study will benefit greatly if twenty or more female students from both the control and treatment groups can be collected during the second trial.

Future work will include completing the second trial of a CURE in IE271 during the Spring 2019 semester. Data analysis, including significance testing if enough returns are gathered, will be completed by July 2019. If the results indicate that a CURE is positively and significantly correlated with increased interest in graduate school for female students, further and more fine-tuned study may be in order. Discussions with the IMSE department's curriculum committee and faculty will ensue.

Acknowledgements

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