

Filling the Graduate Pipeline Via Course-Based Undergraduate Research Experiences (CUREs)

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Abstract

Like many other STEM fields needing workers, the industrial engineering profession will benefit from increased undergraduate retention and an increased number of graduate school applications from women and underrepresented minority populations. Research in the sciences shows that having a significant, hands-on educational experience can affect these numbers, but little has been done to examine this within the field of industrial engineering. In the Industrial and Manufacturing Systems Engineering Department at Iowa State University, we have seen increased graduate school applications result from students participating in undergraduate research assistantships. To increase the number of students having access to undergraduate research opportunities, during the Spring 2018 semester, we implemented a course-based undergraduate research (CURE) pedagogy in a second-year human factors and ergonomics course. This paper describes one of the four research units that was developed and incorporated. The approximately 130 students enrolled in either treatment or control sections were each surveyed; the data were compared with previous undergraduate research data. This work establishes the baseline needed for longitudinal tracking of student retention and graduate school applications related to CUREs in an industrial engineering course. Lessons learned regarding transitioning a course from a traditional lecture format to a CURE pedagogy are included.

Keywords

CURE, research, ergonomics, retention, graduate school

1. Introduction

1.1 STEM Workforce Population Gap

The need for STEM employees is growing at a much higher rate than non-STEM jobs, but the number of available workers for these STEM positions is lagging. According to Change the Equation (changetheequation.org), which has companies like Google, Merck, 3M, and Caterpillar supporting its work, between 2017 and 2027, STEM jobs will grow by 13%, while all other jobs will grow 9% [1]. The Education Commission of the States Vital Signs (vitalsigns.ecs.org) cites the gap in the number of women and people of color who become STEM professionals [2]. While these two groups make up more than half of the U.S. population, they are much less likely to pursue STEM careers. In 2015, the number of engineering degrees and certificates awarded to men was more than three times higher than that awarded to women (127,093, vs. 34,651) [2]. The percentage of underrepresented minority students who have earned engineering degrees and certificates has essentially remained stagnant over the past two decades [2]. With the number of STEM jobs expected to continue growing rapidly, the future of innovation and technology will require more women and minorities to pursue careers in STEM fields if needs are to be met [3].

The largest loss of Iowa State University (ISU) students in STEM disciplines occurs within the first two years of college [4]. Aggregate snapshot data from the Industrial and Manufacturing Systems Engineering (IMSE) Department advising office shows that 11% of undergraduate students change to a different major within their first two years in the program, with approximately 8% of these students going to non-STEM fields. One type of significant educational experience, which affects undergraduate students' decisions about their choice of major and continuation to graduate school, is undergraduate research [5,6].

1.2 Undergraduate Research Experiences

Undergraduate research provides students with many beneficial opportunities, including improving critical thinking and communication skills, practice with working on real-life problems and solutions, engagement with a mentor and/or faculty, and an increased knowledge of disciplinary focus. Undergraduate research allows students to practice creativity, invention, and problem solving, and is more likely to better prepare students for the STEM workforce than passive pedagogy [7]. Undergraduate research assistantships (URAs) are similar to internships and involve students working one-on-one with faculty and/or graduate students. The number of students who can participate in URA experiences is limited to the capacity of the faculty. Similar in impact but significantly different in capacity are CUREs: course-based undergraduate research experiences. CUREs allow large numbers of students to participate in research, and like other undergraduate research experiences, improve students' analytical and technical skills [8-10]. A CURE gives all students in a course the unique opportunity to apply course material using methods that a traditional lecture classroom cannot provide. How students perceive the usefulness of course content affects their enthusiasm in the classroom and as a result, their eagerness to continue pursuit of their STEM major. Establishing relevant and hands-on course material that is applicable to students' potential future careers has been connected to student success [11]. In a hands-on engineering project course for first-year students at the University of Colorado Boulder, it was found that women and ethnic minority students had much higher retention gains [12] compared to traditional lecture format. Besides increasing retention rates, undergraduate research has been shown to affect interest in graduate school [3,5,13]. Research experience in a specific discipline allows students to make better decisions about what discipline they prefer and whether or not they want to pursue graduate school [4,8,10,14].

The IMSE Department at ISU has experienced the positive impact of undergraduate research experience on graduate school applications firsthand. From 2011 to 2015, more than 25% of URA students applied to graduate school, compared to the general industrial engineering graduating senior population of 3.3% [8]. URA students indicate that they are influenced by the opportunity to assist professors in research areas relevant to their major and to work alongside graduate students and other undergraduates doing research. Self-confidence is noted to be an additional benefit of undergraduate research, often through the practice of discovery [3,7,9]. Additionally, students who have participated in research experiences have informally shared that they have increased confidence with speaking skills from giving poster presentations of their research.

To quantify how our URA students' opinions change about graduate school, we began using Dr. David Lopatto's (Grinnell College) SURE III survey in December 2016, which had approval from the Grinnell College Institutional Review Board (IRB). Students complete the SURE III survey immediately after having an undergraduate research experience [15]. In December 2016, 23 of our participating URA students (most department-funded, but some faculty-funded), and again in April 2017, a different set of 23 URA students (though there was some cross-over from one semester to the next) voluntarily responded to Dr. Lopatto's survey questions about graduate plans. Because the two sets of 23 students included some of the same students, we can't add the numbers, but we can look at each individual semester. As previously reported, in the Fall 2016 Semester, aggregate data show that the number of students who considered graduate school as a possibility increased from 1 to 6, with an increase of 4 students (from 1 to 5) responding positively to now planning to pursue a PhD and an increase of 1 student (from 2 to 3) responding positively to now planning to pursue a master's degree [8]. We report similar survey results for the Spring 2017 Semester. Among a different set of students (potentially some crossover with the Fall 2016 cohort, but not all), 7 out of 23 in total reported that they had not considered graduate school prior to their URA experience; afterwards, two additional students reported that they intended to get their Master of Science degrees, and three students reported that they consequently intended to get their PhDs. The results, which also show all national 2016 SURE III survey respondents, are shown in Table 1.

Table 1: SURE III Survey Results for Fall 2016 and Spring 2017 IMSE URA Students

Survey question about post-undergraduate plans	IMSE Students, Fall 2016		All Students, Fall 2016		IMSE Students, Spring 2017		All Students, Spring 2017	
	Before Project	After Project	Before Project	After Project	Before Project	After Project	Before Project	After Project
I had not considered post-undergraduate education	6	1	238	84	7	5	145	44
I planned not to pursue education	7	7	162	121	8	6	122	83
Masters in science field	7	7	598	607	4	6	383	384
Ph.D. in science field	1	5	1166	1349	0	3	735	867
Masters in nonscience field	2	3	76	78	3	3	82	73
Ph.D. in nonscience field	0	0	54	73	0	0	38	44
Medical degree	0	0	854	747	0	0	512	447
Law or professional degree	0	0	67	66	0	0	38	46
TOTAL STUDENT RESPONDENTS	23	23	3215	3125	22	23	2055	1988

Because of faculty time constraints, our department is only able to accommodate approximately 30-40 students/year (out of approximately 600 in the department) with our URA program. Our goal is to increase both retention and the number of students applying to graduate school by increasing the number of industrial engineering students that have undergraduate research experiences. To accomplish this goal, we have implemented the first CURE in the department. In the following sections, we describe the course, one of the four research units that have been developed and added to it, the initial baseline data collection, and goals for post-CURE implementation.

2. Methods

2.1 Applied Ergonomics and Work Design Course

Applied Ergonomics and Work Design is a required sophomore-level course that teaches undergraduate students the basic concepts of ergonomics and the impact that work design has on workers and workplace productivity. This 3-credit course is taught in the spring semester. It is split into two sections and taught by two different professors, but both sections emphasize the same fundamental concepts and content. Historically, both faculty members have taught this course in purely lecture format.

Starting in the Spring 2018 Semester, one section of this course is being taught using a CURE pedagogy (the “treatment” group), while the other section remains unchanged (the “control” group) with a traditional lecture pedagogy. When registering for classes, students were unaware of the planned difference between the two sections. They could switch sections if necessary (e.g., best fit for their class schedule, not meeting a prerequisite, etc.) after spring semester classes started, per department policy. It is possible that after classes started, students might have become aware of the differences between sections and decided to switch (based upon availability); however, only two students switched sections after the first day of class. We note this because while initial placement in sections was relatively random, there could have been some informed changes to the treatment group based on student preference after the semester started. However, if this was the case, it had a very small impact.

This course is an excellent test-case for CURE implementation for several reasons. Because it is a required, introductory course, it provides an early opportunity to introduce research to undergraduate students. Early exposure is potentially more influential on students’ academic and career paths, compared to CURE participation later in their coursework [16]. The course is taught by a professor who is highly involved in research and has access to real-world data for students to use. Course material is directly applicable to the students’ future careers. The course includes content that involves decision-making and working with people, hence providing subjectivity for the students. Such content can be translated into hands-on learning and research engagement. The estimated breakdown of the course is two-thirds lecture material and one-third research time. The lecture material includes concepts essential for the research experiences, but allows subjectivity and requires critical thinking for the students. The content and concepts of the two sections remains identical (up to professors’ discretions); however, the CURE section has less homework, as most out-of-class time is spent on the research experiences. The CURE section also has the benefit of working in teams, randomly chosen by the professor, where the teams complete each research experience together.

According to The Course-Based Undergraduate Research Experiences Network (CUREnet), the best CUREs provide students the opportunity to employ the following in their coursework: use of scientific practices, discovery, relevant or important work, collaboration, and iteration [16]. Through this course’s research experiences, students build and test hypotheses, analyze data, and revise project plans based on their findings. Students work with real data and work in teams. To make the most effective CURE, we designed the research units to meet each of the approaches that CUREnet suggests are critical.

2.2 Tool Selection Unit

There are four research experiences throughout this course involving the following topics: time study and line balancing, ergonomic risk and manual material handling assessment, tool and equipment selection for work, and environmental factors and work design. All students are required to complete each research experiment. In teams, students are assigned a time slot to complete their research, either with the professor or with a teaching assistant. During this time, each student collects their own data, as well as their team members’ data.

For the tool selection process, students were expected to research and test different power drills and then select the correct drill for construction work. This is applicable to a real-work situation, where they may need to select the correct

tool for the job, and they do not know the best answer beforehand. Tool selection is an often overlooked and rarely taught aspect of work optimization. Proper selection of tools is critical to maximizing performance and mitigating ergonomic risk. Students cycled through all of the available drills and parts, creating iteration of the process. Teams were responsible for how they chose to proceed with this, knowing that each cycle should be completed the same way. Students were also responsible for their determination of viable data.

Five drills were chosen for students to use and in three different drilling positions: overhead, mid-level, and low. After drilling, students then used a screwdriver to complete the process. This was repeated each time. Students kept data on the time spent drilling, the vibration signature of the tool, the electromyography, and the subjective information of the person drilling. To measure vibration levels, students used a high-end vibration sensor. For the electromyography, electrodes were connected to the muscles of the student drilling to monitor their muscle activity.

After the research was complete, teams were required to submit a report on their experience, their data collection results, and what the next steps would be if they were to continue with the tool selection. Once the entire class completed the tool selection, the professor reviewed the process in class and revealed which tool was optimal for the work environment. Students were encouraged to discuss their findings and justifications.

2.3 Initial Baseline Data Collection

We surveyed both the treatment and control groups for comparable statistics at the start of the course. We included questions similar to those in Dr. Lopatto’s (Grinnell College) CURE Survey, as this is part of his ongoing research regarding undergraduate education [17]. We will use the post-survey at the end of the semester. The pre- and post-CURE surveys allow students to evaluate their course-based research experience and provide feedback, which can then be translated to improvements in the course for the following year, along with understanding the impact of the pedagogy. The CURE surveys ask many questions like those on the SURE III survey, including, “After taking this course...” with response options such as “I now plan to pursue a Doctoral degree in a science-related field,” [17]. Through these responses, we will be able to identify the impact of the CURE on its influence regarding graduate school consideration and eventually applications.

From the pre-CURE survey, we see most of the responses of 29 of 40 treatment and 26 of 94 control students in Table 2. The numbers of those in each section who, prior to having a CURE, reported that they intend to get a Masters or PhD in the physical sciences (including engineering) are shown. These numbers establish the baseline for the IMSE Department in terms of “before a CURE pedagogy” was implemented and will be compared to the post-CURE survey data to determine immediate impact.

Table 2: CURE Pre-Survey Results for Spring 2018 IE271 Students

Group	Number of responses	
	Treatment	Control
My goal is to go to graduate school for a Ph.D. degree in the physical sciences (including engineering, math, and computer science).	4	1
My goal is to go to graduate school for a Masters degree in the physical sciences (including engineering, math, and computer science).	5	6
My goal does not include graduate education for at least the near future.	16	17
Total	25	24

We will track demographic information about our respondents so that we can see if women and/or underrepresented minorities are influenced by their CURE experiences differently from other populations. For this first CURE implementation, we share the pre-survey data provided by students in Table 3.

Table 3: Section Comparison Pre-Course Survey Data (Number of Students)

Group	Male	Female	Minority	Graduate School Interest
Treatment	14	15	3	13
Control	14	11	3	8

We will also measure long-term success through departmental interaction with students following the completion of their undergraduate studies. Self-reported data from 89.8% of graduating IMSE students in 2016-2017 showed that

9.5% (none of whom have had an IMSE CURE experience) planned to continue to graduate school (this probably does include some URA students, however) [18]. We will begin tracking how many students who have a CURE experience decide to apply to graduate school. However, since we've implemented our first CURE in a second-year course, it will be two years before we can begin this data collection.

3. Discussion

Our goals with this undertaking include the following:

- Increase the number of industrial engineering students who have undergraduate research experiences
- Increase the active learning opportunities in the industrial engineering curriculum
- Increase the retention of underrepresented populations in the IMSE Department
- Increase the number of students from the IMSE Department who apply to graduate school

Through transformation of a traditional lecture course into a CURE, we have succeeded in meeting our first two goals. By providing a CURE to 40 students in one course, we increased the number of students getting research exposure in an academic year by more than 50%. After successfully implementing this pilot, we intend to convince other faculty to try CUREs in their courses. To track student retention rates, the department will follow the academic careers of the students from both the "treatment" and "control" sections. Records will be kept on the number of students who change their major or leave the university. This data will be compared to years of previous department retention data. Gathering information on graduate school enrollment will be dependent on communication with students about their post-graduation plans. Because we already talk with and survey senior-level students, we will add this question to those conversations and surveys. Records will be kept and compared to graduate school enrollment from previous years. Because we are assuming that graduate studies in non-STEM fields are unrelated to IMSE research experiences (e.g., MBA), we will focus on our influence of students pursuing graduate work in STEM disciplines. We define STEM fields using the NSF STEM Classification of Instructional Programs Crosswalk [19].

We learned many lessons from implementing a CURE pedagogy into IE271, including the following:

- IRB (Institutional Research Board) applications should be developed and submitted as early as possible
- Measurement of retention is challenging because of definitions and process
- High quality research experiences don't have to contribute to the creation of new knowledge
- Students appreciate the idea of being involved in research experiences

As with all studies involving human subjects, we went through the normal Institutional Review Board procedures to be able to collect and report on data associated with evaluating the impact of this study. While this process is always time consuming, having course deadlines associated with the university calendar leads us to recommend that this undertaking should begin much sooner rather than later.

Determining how to measure retention was a challenge, because there are many scenarios that can occur. Since this is a departmental course, we chose to focus on our own department and only measure departmental retention. Another alternative that was considered was retention in a STEM field. This could be a suitable choice of measurement, as students may decide to pursue a different STEM degree. However, these situations might not be correlated to their research experience, since many students change majors during their first two years of college. Our recommendation is to focus on retention most closely associated within the purview of the department.

It is challenging to find meaningful work that many students can research during a semester-long course. In this endeavor, because of the professor's professional connections, students were able to use real-world data to analyze as part of their research. Since this is a critical aspect of a successful CURE implementation, we recommend that sufficient data be available for students to analyze. The majority of the research units in our CURE were problems with known outcomes; however, students were unaware of the best answers until after each unit was completed. The knowledge gained from creating procedure plans, having discovery, and making decisions make this research experience valuable. When doing research, students feel more involved with their department, professors and mentors, peers, and with the scientific community. Furthermore, partaking in research in an undergraduate course is a rarity. Hands-on learning can be a refreshing alternative to lectures, and for some students, their best method of learning.

4. Conclusions

After this CURE implementation, we will create a guide for other engineering departments based on our strategies, suggestions, and outcomes. This required course in the IMSE Department gave 40 students the opportunity to participate in research, something most of them would not have otherwise done. During the CURE, students worked in teams with real data and made decisions based on their findings. We have put methods in place to collect the data necessary to determine the impact of incorporating a CURE in an early required undergraduate industrial engineering course. We believe that by giving IMSE students at Iowa State University research experience early in their coursework, a higher percentage of students, including women and underrepresented minorities, will stay in industrial engineering, and will also choose to pursue STEM graduate degrees.

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