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Implementing a Course-based Undergraduate Research Experience (CURE) into an IE Curriculum

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Since 2013, the Industrial and Manufacturing Systems Engineering (IMSE) Department at Iowa State University (ISU) has provided high-impact education experiences to as many as 35 students/semester (~6% of its student body) through undergraduate research assistantships (URAs). These experiences support ISU's strategic goal of ensuring that students receive an exceptional education, with sub-goals of improving the ISU Experience for underrepresented students, increasing retention and graduation rates for all students, and growing the impact and scope of graduate programs [1], [2]. The number of students who can benefit from this experience in the IMSE Department has plateaued, however, because of faculty time constraints. To significantly increase the number of students having this kind of experience, we are implementing a Course-based Undergraduate Research Experience (CURE), where students address research problems in the context of a class. CUREs benefit students in numerous ways; we are focusing on increasing retention in STEM fields and interest in graduate study. ASEE data from 2016 show that currently 31.8% of industrial engineering bachelor's degrees are awarded to women [3]; an increase in this number would be an example of a positive outcome of a CURE. To assess the effectiveness of CUREs as both a retention tool and graduate school pipeline, the IMSE Department has implemented a pilot CURE in the Spring 2018 semester in one 40-student section of a required, 3-credit, second-year applied ergonomic and work design course. At the end of the semester, data will be compared between two sections of this course: the CURE section and the non-CURE (traditional lecture) section. This project will measure increases in the number of students who have undergraduate research experiences, retention rates within the department, and the number of students who enroll in STEM-related graduate school. This work-in-progress paper describes the methods used to develop the CURE pedagogy, including the research activities and assignments that are being incorporated into the course, along with planned assessments. Baseline data and longitudinal data collection plans are described.

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Implementing a Course-based Undergraduate Research Experience (CURE) into an IE Curriculum

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Abstract

Since 2013, the Industrial and Manufacturing Systems Engineering (IMSE) Department at Iowa State University (ISU) has provided high-impact education experiences to as many as 35 students/semester (~6% of its student body) through undergraduate research assistantships (URAs). These experiences support ISU's strategic goal of ensuring that students receive an exceptional education, with sub-goals of improving the ISU Experience for underrepresented students, increasing retention and graduation rates for all students, and growing the impact and scope of graduate programs [1], [2]. The number of students who can benefit from this experience in the IMSE Department has plateaued, however, because of faculty time constraints. To significantly increase the number of students having this kind of experience, we are implementing a Course-based Undergraduate Research Experience (CURE), where students address research problems in the context of a class. CUREs benefit students in numerous ways; we are focusing on increasing retention in STEM fields and interest in graduate study. ASEE data from 2016 show that currently 31.8% of industrial engineering bachelor's degrees are awarded to women [3]; an increase in this number would be an example of a positive outcome of a CURE. To assess the effectiveness of CUREs as both a retention tool and graduate school pipeline, the IMSE Department has implemented a pilot CURE in the Spring 2018 semester in one 40-student section of a required, 3-credit, second-year applied ergonomic and work design course. At the end of the semester, data will be compared between two sections of this course: the CURE section and the non-CURE (traditional lecture) section. This project will measure increases in the number of students who have undergraduate research experiences, retention rates within the department, and the number of students who enroll in STEM-related graduate school. This work-in-progress paper describes the methods used to develop the CURE pedagogy, including the research activities and assignments that are being incorporated into the course, along with planned assessments. Baseline data and longitudinal data collection plans are described.

Introduction

Student success has been linked to courses containing relevant and hands-on material that can be applied to students' future careers [4]. One way that undergraduate students receive hands-on instruction is through participation in undergraduate research programs. Undergraduate research provides students with many benefits, including improved critical thinking and communication skills, practice working with real-life problems and solutions, engagement with mentors and faculty, and an increased knowledge of disciplinary focus [5], [6]. Undergraduate research allows students to practice creativity, innovation, and problem solving, and is more likely to better prepare students for the workforce than passive pedagogy, like traditional lectures [5]. Increased self-confidence has been identified as an additional benefit of undergraduate research, commonly obtained during the discovery stage of research [7] - [10]. Undergraduate research has also been shown to affect student interest in graduate school [5], [9], [11] - [13]. When students conduct research, they gain a better understanding of their preferred disciplines and whether or not they have an interest in pursuing graduate school [5], [7], [12], [14].

The need for increased student retention and success in STEM fields is driven by the need for STEM employees in industry. NSF's Science and Engineering Indicators 2016 report [15] shows that the greatest disparities in representation between men and women occur in engineering, computer science, and the physical sciences. This same report shows that underrepresented populations like Black/African American and Hispanic groups earn only one-fifth the number of science and engineering degrees that white students do [15]. These gaps persist beyond college. While women and minorities make up more than half of the U.S. population, they are much less likely to pursue professional careers in STEM fields [16]. At the rate that STEM jobs are growing, more women and minorities will need to study STEM fields to keep up with the rapid changes of innovation and technology.

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 majors [4]. The largest loss of Iowa State University (ISU) students in STEM disciplines occurs within the first two years of college [10]. In the Industrial and Manufacturing Systems Engineering (IMSE) Department, data from the advising office shows that approximately 11% of undergraduate students change to a different major within the first two years in the program, with approximately 8% of these students going to non-STEM fields. By providing many more undergraduate students the opportunity to participate in research, our goal is to increase both retention and the number of students applying to graduate school. To provide these research opportunities, we have implemented the first CURE in the department, which is also one of the first CUREs in the College of Engineering at Iowa State University.

IMSE Department Background

Similar to internships, undergraduate research assistantships (URAs) provide students the opportunity to work one-on-one with faculty and/or graduate students. The current URA program in the IMSE Department at ISU has seen overall student success through graduate school applications. From 2013 to 2015, more than 25% of URA students applied to graduate school, compared to the total IMSE graduating senior population of 3.3% [2].

In total, the URA program has had 119 students participate since its inception in 2013. As a comparison, the department reported 492 full time undergraduate students in the 2017 ASEE Profiles [17]. Table 1 shows the breakdown of URA students' post-B.S. study and planned study through the Fall 2018 semester. To date, 22.7% of URA students have applied to, are currently in, or have graduated from post-B.S. programs. Of these students, 4.5% are MBA students. Because NSF defines STEM careers based on the NSF STEM Classification list [18], neither these nor the medical/dental post-B.S. study are considered retention in STEM. Subtracting these out, the IMSE URA program is currently at 17.3% of its participants continuing with graduate study in a STEM field. This number is a floor, based on decisions made while students are still on campus and discussing their plans with IMSE advisors and faculty. We also note that it doesn't include freshmen currently in the program, as they are too young to apply for graduate study, nor does it include the non-industrial engineering students who participate through the Honors Program or are hired by faculty for specific non-IE skillsets. The 2013 U.S. Census Bureau Survey showed that 11.7% of the population held a Masters, Professional, or Ph.D. degree; by comparison, our rate of post-B.S. degree study is significantly above the general population, particularly because the census number includes all degree disciplines, and not just STEM fields [2].

Table 1: Breakdown of Post-B.S. Degree Types, Along with Numbers and Percentages of URA Students Since 2013

Type of Advanced Degree	Number of Students	Percentage*
IE MS - current and graduated	14	12.7%
IE MS - applied for F'18	3	2.7%
MBA - current and graduated	5	4.5%
PhD - current and graduated	2	1.8%
Medical/Dental post-grad applied F'18	1	0.9%
TOTAL Post-B.S. Study	25	22.7%
*not including current freshmen or non-IE students		

Table 2 looks at the breakdown of men versus women in the URA program over the past five years. While the percentage of both female and male URA students continuing to graduate school is similar (23.1% vs. 25.0%, respectively), the percentage of female students choosing an industrial engineering/STEM path over an MBA path is very different from male students (56.6% vs. 93.8%, respectively). We note that 80% (4 out of 5) of our students who have chosen an MBA post-graduate path have been female students, indicating a definite need for analysis.

Table 2: Comparison of URA Women's and Men's Post-B.S. Degree Choices Since 2013

	URAs*	Grad School	STEM Grad School	MBA
Women	39	9 (23.1%)	5 (56.6%)	4
Men	80	16 (25.0%)	15 (93.8%)	1
*includes all students in URA cohort				

We have used Dr. David Lopatto's (Grinnell College) SURE III survey, which has approval from the Grinnell College Institutional Review Board (IRB), since December 2016 to quantify URA students' opinions about graduate study. This survey is for students completing an internship-like research experience; students complete the survey at the conclusion of their experience [19]. One example of the impact of these experiences, previously reported for the Fall 2016 semester, showed that 'the number of students who considered graduate school as a possibility for them 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"' [2]. While we didn't assess the significance of these numbers within or across semesters, anecdotally, they support our premise that exposure to research has an overall positive impact by increasing the number of students who consider graduate school.

Additionally, while we can look at previous URA participants and compare men's and women's graduate school decisions, we have not previously asked for nor assumed that we could identify the minority status of each of our students. Through Lopatto's survey, we have a small sample of URA students' self-reported minority-statuses (e.g., in F'16, 3 out of 24 students reported as Hispanic/Latino). This provides a baseline of comparison between URA and CURE students, but doesn't inform us about the difference between students who have a research experience versus those who don't. However, based on results like those of Kukreti et al., we believe that having a course-based undergraduate experience will positively affect both retention and interest in graduate school for minority students [11]. These positive influences may result from the cohort building and networking that result from a CURE.

Many students have expressed interest in the URA program specifically for the opportunity to work alongside faculty in a particular research area. URA students are required to deliver a poster presentation of their research findings; students have indicated increased confidence with their speaking abilities following their presentations. Additionally, students have enjoyed working with graduate students and other undergraduate research students in the program.

CURE Benefits

Despite recognition of the many benefits, there are not enough URA opportunities available to students in the IMSE Department because of constrained faculty resources [2]. One way to address this is to implement Course-based Undergraduate Research Experiences, or CUREs. CUREs are incorporated into a curriculum, providing students with undergraduate research experience while taking courses that apply toward their degrees. In a typical CURE, the curriculum includes required inquiry and investigation [20]. CUREs have benefits similar to URA experiences, such as improving students' analytical and technical skills [2], [8], [14]. They allow students to use scientific practices, potentially develop something new, collaborate with group members and faculty, and participate in a broader scientific context [8], [20]. CUREs are the connection between laboratory research and classroom lectures, enabling students to see and use the course material in action. While not a CURE, instructors at Montana State University and Northeastern University implemented similarly hands-on, experiential learning exercises in an introductory industrial engineering course. They found that students physically working with problems and seeing how real systems operated were more compelling than traditional teaching pedagogies; students even seemed more enthusiastic about industrial engineering [21]. Many others have reported CURE benefits, including networking and developing scientific skills, as well as outcomes like increased teamwork, critical thinking, communication skills, and confidence [14].

Because CUREs are incorporated into regular coursework, they provide a significantly greater number of students the opportunity to participate in research. This addresses the scale-up issue that the URA and REU (research experiences for undergraduates) apprenticeship models cannot address.

Pilot Program: Methods for Development

Before implementing a CURE in the IMSE Department, there were several important tasks to undertake. We started by investigating if CUREs were already being used within the college and/or university. Discovering that some were, we communicated with faculty who had implemented CUREs and who were part of other research-affiliated groups. At Iowa State University, the Howard Hughes Medical Institute (HHMI) Project provides opportunities for undergraduate students to participate and experience science by transforming traditional classes and labs to those that include inquiry and research, as well as science projects for undecided freshmen students [22]. We met with members of the HHMI Research Lab Faculty Learning Community; they provided insight, materials that they had created, and their own research findings regarding successful CUREs.

Within our department, we considered which classes and faculty might be a good fit for a first CURE. Through our URA program, we had (and continue to have) excellent exposure to the research of participating faculty, including their research areas and levels of interest in trying new pedagogies. We also had (and continue to have) survey data and baseline knowledge about student choices regarding graduate school. We considered these things when making our decisions about which faculty to approach, which course to try, and what the research curriculum might look like for integration of undergraduate research experiences as part of a pilot program.

Applied Ergonomics and Work Design (IE271) is a second-year, required, introductory human factors course that covers the basic concepts of ergonomics and work design impact. It is three credits, taught in two sections during the spring semester, by two industrial engineering faculty members. Both faculty members are highly involved in research, and both emphasize the same fundamental concepts and content in their sections. Historically, both faculty members have taught this course using a purely traditional, lecture format.

The course was identified as an excellent one for the department's first CURE pilot for several reasons. First, introducing research in the second year of students' required curriculum provides an earlier opportunity to teach them about what research entails. Second, introducing research in a required undergraduate course ensures that a broader selection of students will be involved. Many undergraduate students complete research internships late in their college career, reducing the impact on their educational experiences [13]; Auchincloss, et al., note that early exposure is potentially more influential on students' academic and career paths [23]. Third, because the course includes making decisions about people, it has inherent subjectivity. This facilitates hands-on learning and research engagement. Fourth and finally, one of the faculty members who teaches the course has access to extensive real-world data which students can use, and is very enthusiastic about implementing a CURE into his classroom.

According to The Course-Based Undergraduate Research Experiences Network (CUREnet), the best CUREs provide students the opportunity to engage in the following five ways: use of scientific practices, discovery, relevant or important work, collaboration, and iteration [23]. Concurring with CUREnet, we wanted to implement these techniques as we designed our CURE. Many decisions were made, including how many research "units" to include in the course, what the time balance between traditional lecture and research should be, the type of research that students should do and in what ways, and how these activities should be assessed. Beginning in the Spring 2018 semester, the CURE was implemented into one section (the "treatment" group), while the other section retained the traditional lecture format (the "control" group). The content of the two courses remained the same, but the methods for delivery were changed. The CURE section asked students to spend their "out-of-class" time performing research in teams, and consequently had less individual homework.

There are many examples of CURE implementation in the literature. We didn't find any that exactly matches ours, though it's possible that it exists. We found little related specifically to industrial engineering. More common were similarities with techniques in non-industrial engineering courses. At the University of North Carolina at Pembroke, students performed research experiments in an upper-level biology course [8]. For the first seven weeks of the course, students learned basic molecular biology techniques related to their specific research. The following seven weeks consisted of the research experiments performed. In our CURE, we chose to integrate the research experiments and the lectures. Doing this allows students to learn the important concepts and then immediately apply this information to a hands-on learning experience. Another example of CURE implementation comes from an undergraduate aerospace engineering course at a mid-Atlantic research university, which had students work in small groups on a research project, usually related to their graduate mentors' theses/graduate work, and involved hands-on learning [12]. For the first few weeks of the course, the instructors taught in a traditional lecture format to introduce important concepts. The rest of the semester, students worked on their projects with their groups. Our CURE differs from this in that the undergraduates' research is specific to the instructor's research, and as previously noted, our pilot CURE has traditional lecture interspersed with different research experiences throughout the entire semester. We decided to implement four research units throughout the semester, with an estimated breakdown of two-thirds lecture material and one-third research time. The four units are described in the next section. During each research unit, students build and test hypotheses, analyze data, and create project plans of action. Students also work through real-life problems with their teams.

We note that prior to the semester starting, when students were registering for classes, they were unaware of the planned difference in pedagogy between the two sections. Based on advice from our benchmarking with the HHMI Research Lab Faculty Learning Community, it was important that the populations of the two sections remain randomized. We did not want students already interested in or predisposed to liking CUREs purposely choosing the CURE section. For this reason, we did not advertise or inform students about the planned difference between the sections. Out of a total of 134 students (40 in the CURE section, 94 in the traditional lecture section), only two changed sections after the first day of class, and this was for scheduling reasons. We note that for this pilot semester, the CURE section started with 110 available seats, and the traditional section had 100 available seats. We think the large difference in students registered was a function of schedules for the S'18 semester.

Pilot Program: Research Activities & Assignments

In the CURE section of IE271, there are now four research experiences 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. These research experiences were chosen because of their applicability to real-work situations, as many industrial engineering students will be working with people to solve similar types of problems. All students are required to complete each research experiment. Teams of students are assigned a time slot to complete their research, either with the professor or with a teaching assistant. During this time, students collect their own data, as well as assist their team members with data collection. Students collect cycles of data, creating iteration of the process. Teams are responsible for how they choose to conduct their research, knowing that each cycle should be completed consistently. Students are also responsible for differentiating between viable and nonviable data. After each research unit is completed, teams are required to submit a report on their experience, their data collection results, and what their next steps would be if they were to continue with the research process. Once the entire class completes a research unit, the professor reviews the process in class and, depending on the research unit, discusses "best answer" findings. Students are encouraged to discuss their findings and justifications.

These labs, which are all related to actual past research projects, are all designed to give the students practical experience that is then used in a group project. The group project is an actual real-world research project. The students go on-site with a professional dive rescue team and perform analysis of all operations and tools. The students' end reports focus on the application of work design and ergonomic analysis. Each group presents and defends their findings to the professional dive team and the course professor. Based on review of the literature, we are unaware of any other CURE experiences that utilize past research projects as laboratory exercises, and combine them with a new current project as a practical experience.

Time study and line balancing research experience: students simulate building small cars. They are first given directions on how to perform the basic assembly (done with small scale structural pieces). They are then instructed to perform time studies, line balancing, and job task analysis. After this is completed, they must report on critical work tasks and devise alternative work methods. They then conduct an additional analysis and report on their findings.

Material handling assessment research experience: students are given a total of six different work place activities involving material handling. They are taught how to use four different ergonomic risk evaluation tools. Each group member must perform each work task and be evaluated by their team members. Risk findings are analyzed and each group reports on the risk and the usefulness of each risk identification method.

Tool selection research experience: students must research and test different power drills and then select the best drill for construction work. Five drills with three different drilling positions (overhead, mid-level, and low) were chosen for students to test. After drilling, students use a screwdriver to complete the process. This is repeated, with all students cycling through the available drills and parts. Students collect and analyze data on drill times, the vibration signatures of the tools, the electromyography, and the subjective information of each person drilling. To measure vibration levels, students use a high-end vibration sensor. For the electromyography, electrodes are connected to the muscles of the student drilling to monitor their muscle activity. Students must determine the best tool selection to maximize performance and minimize ergonomic risk.

Environmental factors and work design research experience: this task directly mimics the faculty member's research. This unit involves the proper selection of heat mitigation technology for law enforcement officers. Students are exposed to both moderate and high temperature environments and are given different cooling technologies. They observe thermal and other environmental sensors in addition to user feedback to determine the best mitigation technologies. Following this, students report their findings to actual law enforcement officers.

Pilot Program: Planned Assessments

Student understanding of course material is assessed through assignments and exams. Course effectiveness will be assessed in terms of student work quality analysis, outcome attainment, and student feedback. The depth of understanding of the students and the external review of work content will be used to determine the impact of the pedagogy. Comparisons of student attitudes about pedagogy, as well as potential graduate school, will be compared between the treatment and control group sections of the course, as well as within each section between the pre- and post-treatment surveys.

Data Collection

Baseline data collection began during the Spring 2018 semester. During Week 4, just prior to the divergence between the pedagogies in the two sections of IE271, students in both the traditional and CURE sections were given two optional pre-CURE surveys. One survey was the CURE Survey by Dr. David Lopatto of Grinnell College, which is part of his continuing research on undergraduate education [24]. The other was a similar survey constructed by the authors, which contained some different questions, and was included so that data could be compared internally. We note that prior to the distribution of the surveys, IRB approval was obtained from ISU's Institutional Review Board.

Post-surveys will be distributed to the students at the end of the semester. The surveys ask questions like "After taking this course…" with response options such as "I now plan to pursue a Doctoral degree in a science-related field," [24]. See Table 3 for example questions. We will use the students' responses to identify the impact of the CURE on their plans for post-graduate education. The data from pre- to post-surveys will be compared to determine if the CURE pedagogy has a significantly different outcome than the traditional lecture pedagogy. We will use this information to inform our departmental teaching strategies.

Table 3: CURE Post-Survey Questions

Rate possible benefits you gained from your research experience, from "no gain or very small gain" to "very large gain" (1 to 5)	Average Response	
Group	Treatment	Control
Self-confidence		
Ability to analyze data and other information		
Readiness for more demanding research		

We already have baseline graduate school data based on self-reported responses by students regarding post-bachelor degree plans for both the URA and general industrial engineering student populations. With this new CURE pedagogy in place, and consequently increased exposure to hands-on research for approximately one-third of our students, we will continue to track and compare this data to see if there is an increase in the number of students remaining in STEM fields (retention) and the number continuing to graduate school. Students can self-report gender and minority status during the pre- and post-CURE survey process, as well as in other departmental surveys throughout their education. This data will also be collected, shown in Table 4, as well as similar data from post-course surveys.

Table 4: Section Comparison Pre-Course Survey Data (Number of Students)

Group	Male	Female	Minority	Graduate School Interest	Previous Research Experience
Treatment	14	15	3	13	2
Control	14	11	3	8	3

We note that we define retention as “remaining in a STEM field.” We also note that we are defining STEM occupations based on the NSF STEM Classification list [18]. To measure retention, we will keep track of all students who transfer out of our department. Aggregate numbers of students who transfer to non-STEM fields and students who transfer to different STEM fields will be determined on a yearly basis. As the advising office remains in contact with graduating students about their post-graduate plans, we will add an additional question to this communication to cover this objective. Because IE271 is a sophomore-level course, we will not have much data until Spring 2020, when the students who are currently taking the course get closer to graduation.

After our first semester of using a CURE pedagogy in a course is complete, we will create a guide for the College of Engineering at Iowa State University to facilitate wider dissemination. We will provide recommendations based on lessons learned from this pilot and will encourage other departments to integrate research within their coursework. From the post-CURE survey data, we will also consider recommendations from students on course improvements. Because continuous improvement is an integral part of our departmental processes, as our CURE pedagogy improves, we will update our implementation guide to match those improvements and recommendations for others.

Conclusion

The importance of increasing retention and encouraging more students to consider graduate school cannot be overstated, particularly for students from underrepresented groups. For example, at 31.8% female, the industrial engineering profession has “reasonable” representation, but this could certainly be improved. Because classroom experiences can affect students’ short-term (stay in the major?) and long-term (go to graduate school?) decisions, and because we’ve seen ongoing, positive results from our one-on-one undergraduate research assistantship program, we are making the leap to course-based undergraduate research experiences in a pilot program during the Spring 2018 semester. For the first time, we will formally collect information about student demographics, including self-assessed minority status. We will measure and compare student attitudes about industrial engineering as a major and future profession, along with opinions about potentially attending graduate school. We will compare this data across pre- and post-treatment surveys, and we will also compare it between treatment and control groups. The results, some of which will be immediate in nature (e.g., desire to pursue graduate school), and some which will be longitudinal in nature (e.g., actual retention numbers and applications to graduate school) will be shared as they are available. These results will also be used to inform other departments in our college so that they might benefit from lessons learned with the implementation of such a program. If this CURE is successful, we will also look at applications in junior and senior level courses, so that students can continue to reap the benefits throughout their undergraduate careers. Having exposure in their junior and senior years will most likely also influence their graduate school decisions. In this work-in-progress paper, we have explained our motivation and baseline. We will report short- and long-term results in the months and years to come.

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