Course-based Undergraduate Research Experiences (CURE) in Engineering Technology

William Hutzel, Purdue University

William Hutzel is a Professor of Mechanical Engineering Technology at Purdue University in West Lafayette, IN, where he teaches and conducts research related to High Performance Buildings.

Craig Zywicki, Purdue University

Craig Zywicki is an Associate Director of the Office of Undergraduate Research at Purdue University in West Lafayette, IN. He has twenty years of experience in higher education at four different institutions, with responsibilities in research/assessment, teaching and learning, and holistic student development.

Dr. Stephanie Gardner, Purdue University

Stephanie Gardner is an Associate Professor and the Associate Head for Curriculum, Teaching, and Learning.in the Department of Biological Sciences at Purdue University in West Lafayette, IN.

Course-based Undergraduate Research Experiences (CURE) in Engineering Technology

Abstract

Although most universities provide excellent research experiences for outstanding undergraduate students, the number of interested students typically outstrips the supply of faculty and graduate student mentors. Addressing this shortfall is the reason Course-based Undergraduate Research Experiences (CUREs) were created. CUREs face obvious challenges because they operate at a larger scale than the traditional apprentice-based model for undergraduate research, creating resource issues for experimental research that requires equipment, laboratory space, and staff oversight. To help address these hurdles, one university has created a professional development program that provides training, collegial mentoring, and financial support to interested faculty. This paper provides an overview of the CURE program from the perspective of a faculty member who has created CURE content in Engineering Technology and served as a mentor for other faculty pursuing this style of teaching. The purpose is to stimulate discussions of best practices and encourage new faculty to participate.

Introduction

The Council on Undergraduate Research and the AAC&U identifies several positive outcomes from student participation in undergraduate research, such as career preparation, student retention, and the development of critical thinking and problem-solving skills (Kuh & Schneider, 2008; The Council on Undergraduate Research, 2018). In addition to these benefits, students in science majors, for example, have reported increased content knowledge and technical skills, confidence in their ability to do science, and improved persistence and success in their majors (Dolan, 2017). Data from Purdue University supports these findings. Results from the inaugural Gallup-Purdue Index illustrate the importance of students engaging in significant experiential learning, particularly in-depth opportunities (e.g. internship or long-term class project), as well as strong mentorship from faculty (Purdue University, 2014).

Purdue has a long history of providing quality Undergraduate Research Experiences (UREs) using primarily an apprenticeship model, which requires one-on-one mentorship within a research team. However, while over 3,800 students participated in at least one URE during the 2022-2023 academic year at Purdue, an increasing undergraduate student enrollment coupled with the significant time and resource investment required from faculty mentors, make it difficult for the university to rely on the apprenticeship model to provide UREs for all students.

To address this challenge, the Office of Undergraduate Research at Purdue University made a strategic investment in Course-Based Undergraduate Research Experiences (CUREs) to engage a larger number of students. CUREs provide a larger number of students with access to valuable experiential learning opportunities in which they will learn and use the practices of their disciplines and be a part of the discovery of new knowledge. The Purdue CURE program trains instructors to incorporate novel research into existing or new courses and maintains a collegial community of practice so that faculty can learn from successful efforts of their peers.

A CURE is a specific URE model occurring within a for-credit course that includes a novel research experience and is holistic, engaging students' creativity and ownership in the discovery process and presentation. The research experience can run for an entire semester or be a module within a course. CUREs engage students in the entire process of discovery from creation of questions through presentation of findings and have been successfully delivered in a wide variety of undergraduate courses. Although CUREs have been offered at all levels of the four-year undergraduate curriculum, research intensive classes for students with sophomore to senior standing are regularly offered. CUREs for first-year students are less common.

The leading barrier to developing new CUREs, cited by instructors, is time (Spell et al., 2014). As opposed to a traditional undergraduate course, additional planning, resources, and departmental support are needed to successfully deliver a CURE. This is why the Purdue CURE program offers a professional development program so that instructors across a range of disciplines have dedicated time and support for designing a CURE. Participants in the Purdue CURE program are provided with guidance on course design along with one-on-one instructor mentorship and peer support. The program has five key components:

1. A faculty/staff leadership team with CURE expertise and resources
2. An interactive two-day workshop during the summer to plan each CURE
3. A faculty peer-group for collaboration during the academic year
4. A faculty peer-mentor to provide on-on-one support during the academic year
5. A financial incentive of approximately $2,500 for completing all elements of the CURE

The ongoing programmatic results show that CURE has been successful at engaging large numbers of students and faculty. Since the program started in 2019, there have been five academic year CURE cohorts. In that time more than 3,500 students in more than fifty different courses have been involved in a course-based research experience. It is also encouraging that the participation has included most of the colleges at Purdue. The 2023-2024 academic year cohort includes faculty from Agriculture, Business, Education, Health & Human Sciences, Honors College, Liberal Arts, Libraries, Pharmacy, Technology, and Science.

There are certainly challenges with delivering a high-quality research experience in a large-course environment. For experimental research, one obvious constraint is the resource limitations for undergraduate research teams to access laboratory facilities and equipment. Ensuring student safety for some types of laboratory work can also be a significant factor. The laboratory-based impediments can be mitigated by focusing on research driven by modeling and simulations instead of experimental research. Even then, faculty cite the lack of instructional time for students to develop expertise with computational tools as a significant challenge.

Overcoming these types of limitations is one of the primary reasons for the mandatory two-day workshop as a launching point for each new cohort of CURE faculty. The CURE leadership team help new faculty think through the logistics of a research topic of the faculty member's choosing. This type of detailed planning, in addition to conversations about diversity, equity, and inclusion, go a long way towards making sure CURE projects are feasible and successful at some level, even though "success" is not typically measured in terms of a significant discovery or a journal publication.

Significant efforts have been made to assess the impact of CURE from a student's perspective. The results of these surveys are the targets of other pending academic publications but suffice it to say that most students appreciate and benefit from the research experiences that they have received. The remainder of this paper describes one faculty member's experience as both a CURE participant and a CURE mentor.

CURE in Engineering Technology

A Mechanical Engineering Technology faculty member became interested in a CURE experience for students in a capstone elective focused on HVAC Design. An open-ended project had always been an important element of this laboratory-based course, but these projects were typically routine HVAC design work conducted with an industry partner. While these real-world projects were beneficial, it is also advantageous to pursue more innovative projects that align with the pressing challenges facing the HVAC industry related to climate change.

According to the Energy Information Administration of the U.S. Department of Energy, buildings consume more than 40% all energy used in the United States and 70% of the electricity. New technologies are needed to "de-carbonize" the design and operation of residential and commercial buildings. Another significant research area in HVAC design is related to improving Indoor Environmental Quality to benefit the health and well-being of building occupants. The ultimate motivation for joining the Purdue CURE program was to broaden the scope of senior-level capstone projects, generate new topics for research and publications, and create new pathways to identify and recruit new graduate students.

The HVAC design course is offered once each academic year to senior level students. The course is delivered with two one-hour lectures and one two-hour lab each week. With approximately twenty students in a typical course, two lab sections (ten students each) are needed. Of particular importance for developing and delivering the CURE, this course is taught in the Applied Energy Laboratory (AEL) so that students have access to facilities and equipment for conducting research.

The AEL is a unique 2,000 ft^2 facility for teaching and research featuring HVAC systems, building controls, and solar energy systems. As an example, Figure 1 shows a small commercial air handler (left) that is monitored and controlled by a web-based building automation system (right). This equipment is connected to an environmental chamber that is heated and cooled independently of the larger building where the AEL is located. Students have full control of the thermal comfort conditions inside this test facility for conducting their own research. Access to the AEL alleviated many of the resource concerns that can be problematic for CUREs.

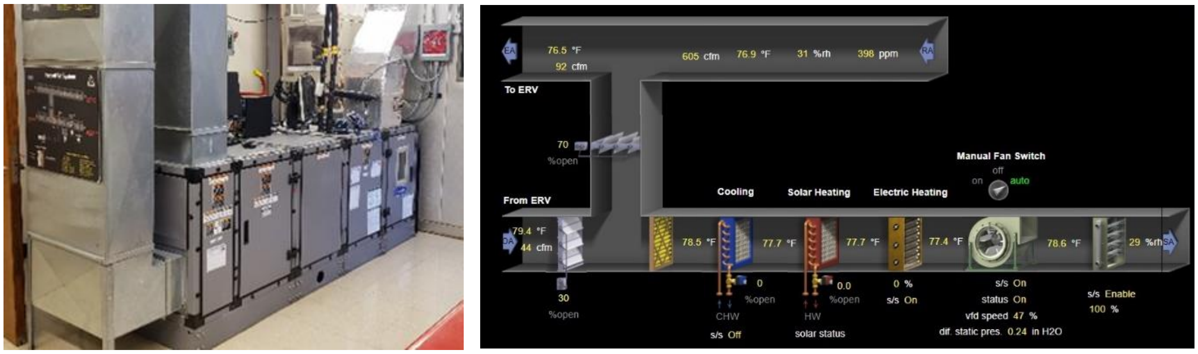

Figure 1. HVAC equipment (left) and accompanying Building Automation System (right).

The first nine weeks (60%) of the HVAC CURE course was traditional lecture and laboratory topics related to HVAC design. Some of this material was either condensed, modified, or omitted to make room for the research component of the course. For example, a new course module on measurements and instrumentation was created to emphasize the importance of accuracy, precision, and the use of significant digits in recording experimental data. Assignments related to data management were also developed so that students were familiar with the basics about creating and maintaining archival quality research data.

The research component was delivered in the last six weeks of a 15 week semester, roughly 40% of the overall course. Although there were no formal lectures during the research phase of the class, Table 1 summarizes the technical topics and assignments that were delivered on a just-in-time basis as the research work progressed. This framework was developed to provide a research framework for undergraduate students who had not done this type of work before. Each element is described in more detail below.

Table 1. Elements of HVAC CURE course.

Course Topic	Assignment
1. What is Research?	Responsible Conduct of Research Training
2. Problem Identification	Literature Review
3. Research Planning	Research Proposal
4. Data Collection & Analysis	Weekly Updates
5. Reporting	Final Report & Presentation

What is Research? reinforced students' understanding of the experimental method. Additional emphasis was given to research ethics, culminating in students completing an online tutorial on the Responsible Conduct of Research that is mandatory for students and faculty conducting research in the Polytechnic Institute at Purdue University.

Problem Identification taught students the basics of conducting a literature review and referencing their sources. After students had a preliminary idea of their project's focus, students were required to identify and reference at least three recent publications related to their work.

Research Planning forced students to develop a strategy for completing their research. Students submitted a formal research proposal that identified a research question, scope of work, safety assessment, and budget. This planning was essential for determining the project's feasibility.

Data Collection / Analysis lasted for three weeks. During this time students conducted their research and submitted weekly updates on their progress.

Reporting required students to submit a final report and make a presentation of the findings. Students had the option of participating in the campus-wide Undergraduate Research Symposium that is held at the end of every semester.

The HVAC CURE was delivered by breaking the class up into five four-person project teams where everyone had a specific role. The project manager focused on meeting project deliverables. Two students focused on data collection/analysis and another student had primary responsibility for documenting the research results. This division of labor was important for getting all students actively engaged in completing the research project in a timely manner.

Due to the timing of this course in the Fall of 2021, the immediate aftermath of COVID restrictions, all the student projects were on the topic of Indoor Environmental Quality (IEQ). Students self-selected their project with guidance from the instructor. Table 2 lists the five student projects. All of the projects used a quantitative approach. Most projects used a lab-based experiment but one team used numeric modelling.

Table 2. Course-based research projects for Indoor Environmental Quality.

Topic	Approach	Project Quality
Indoor Air Quality Factors Impacting Patient Health & Comfort	Modelling	Low
The Study of Moisture Content and Pressure Drop in a Biowall System	Experimental	High
Volatile Organic Compound Reduction by Ionization Generators	Experimental	High
Performance of Low-cost Indoor Environmental Quality Sensors	Experimental	High
Impact of Biofiltration on Indoor Environmental Quality	Experimental	Medium

Table 2 also includes an instructor-based qualitative assessment of the overall quality of the research in the right column, broadly categorized as either "High", "Medium", or "Low". Three of the five projects were rated "high" because they successfully tested a valid research question. One of the projects was rated "Medium" because it did not fully follow the experimental method. One of the projects was rated "Low" because it did not yield valid data. In hindsight, the "Low" rating was probably because the modelling approach was beyond the ability of the student team.

Although the instructor did not assess whether intrinsic student motivation (e.g. student interest) had an impact on achieving satisfactory research outcomes, the instructor noted that all student teams struggled with 1) stating a measurable research question and 2) developing a feasible scope of work that could be achieved during a six week research project that only included about three weeks of data collection and analysis. These mixed results point out some of the challenges of the CURE approach. It is likely that these shortcomings would be more pronounced in courses with larger enrollments and more limited resources for one-on-one interactions with students.

The student feedback on the HVAC CURE course was generally favorable. In the end of course evaluation, 83% of the students "Strong Agreed" with the Likert Scale statement that *"The course projects and laboratories aided me in achieving the class objectives."*. However, in the anonymous written feedback one student expressed disappointment because the research-focused course did not fully deliver on its traditional HVAC objectives. The student stated *"I feel like this course was not about HVAC as much as it was other topics"* and *"I wish the course would be put more onto the subject of various HVAC systems and the technology behind them"*.

CURE Mentoring

The faculty member who developed and delivered the HVAC CURE continued their CURE involvement by becoming a peer mentor in succeeding academic years. The peer mentor position became necessary due to the growing popularity of the CURE program on the Purdue University campus. The mentor commitment includes participating in the two-day summer CURE training program and providing guidance to a 5-person cohort of faculty mentees as they progress through their own academic year journey to develop and deliver their own CURE.

An obvious goal for a CURE mentor is sharing best practices for undergraduate research. One challenge for mentors is working with different disciplines because the expectations for research are not the same (e.g. Research in Science is different than research in Business.) That is where the broader CURE framework comes into play. The overall CURE community of practice, which includes CURE administrators, can provide helpful guidance and support.

Conclusions

A large R1 university is engaging large numbers of undergraduate students in genuine research experiences by providing a support system for creating and delivering Course-Based Undergraduate Research Experiences (CURE). The CURE program includes training, mentoring, and a collegial community of practice. This support is essential for faculty because leading undergraduate research takes a significant amount of time and resources. The results so far are encouraging based on the large participation by faculty and the feedback received from students. CUREs will not replace the traditional apprentice-based model for giving undergraduate students research experience, but CUREs can be beneficial for faculty seeking to move their research into their undergraduate classrooms.

References

1. Auchincloss, L. C., Laursen, S. L., Branchaw, K. E., Graham, M., Hanauer, D. I., Lawrie, G., McLinn, C. M., Pelaez, N., Rowland, S., Towns, M., & Trautmann, N. M. (2014). Assessment of course-based undergraduate research experiences: A meeting report. CBE—Life Sciences Education, 13(1), 29–40. https://doi.org/10.1187/cbe.14-01-0004

2. The Council on Undergraduate Research. (2018). Mission and History. https://www.cur.org/about/mission-and-history/

3. CURE as pedagogy. (n.d.). CUREnet. https://serc.carleton.edu/curenet/pedagogy.html

4. Dolan E.L. (2017). Course-based Undergraduate Research Experiences: Current knowledge and future directions Commissioned paper for the Committee on Strengthening Research Experiences for Undergraduate STEM Students. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_177288.pdf

5. Dolan, E. L., & Weaver, G. (2021). A guide to course-based undergraduate research. Macmillan Learning. https://store.macmillanlearning.com/us/product/A-Guide-to-Course-based-Undergraduate-Research/p/1319367186

6. Kuh, G., & Schneider, C. G. (2008). High-impact educational practices: What they are, who has access to them, and why they matter. Association of American Colleges and Universities. https://www.aacu.org/publication/high-impacteducational-practices-what-they-are-who-has-access-to-them-and-why-they-matter

7. Purdue University. (2014). Gallup-Purdue index releases inaugural findings of national landmark study. https://www.purdue.edu/newsroom/releases/2014/Q2/gallup-purdue-index-releases-inaugural-findings-of-nationallandmark-study.html

8. Responsible Conduct of Research (RCR) | CITI Program. (n.d.). CITI Program. https://about.citiprogram.org/series/responsible-conduct-of-research-rcr/

9. Spell, R. M., Guinan, J. A., Miller, K. R., & Beck, C. W. (2014). Redefining authentic research Experiences in introductory biology laboratories and barriers to their implementation. CBE—Life Sciences Education, 13(1), 102–110. https://doi.org/10.1187/cbe.13-08-0169