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# Course-based Undergraduate Research Experiences (CUREs) for Computer Science?

Ernst Bekkering
bekkerin@nsuok.edu
Mathematics and Computer Science
Northeastern State University
Tahlequah, OK 74464

## Abstract

Undergraduate research can stimulate students' interest, especially in STEM disciplines. This research can be formally offered in different formats as Undergraduate Research Experiences (UREs). One of these is Course-based Undergraduate Research Experiences (CUREs), which are offered as in integral part of scheduled courses. CUREs have been primarily offered in Biological Sciences and Chemistry. A repository of CUREs (CUREnet) has been published with support of the National Science Foundation. This paper presents an opportunity to develop CUREs in Computer Science. It describes the content of the first authentic Computer Science CURE on CUREnet and provides links to all online materials. Students in the class completed a survey based on the Persistence in the Sciences (PITS) scale. Quantitative analysis did not demonstrate any effect on recruitment or retention. Analysis of qualitative responses was more positive. While the specific student research experiences on CUREnet are only of use in other disciplines, their use has proven beneficial in student recruitment and retention in those majors. CS faculty have an opportunity to use the model within Computer Science and get similar results.

**Keywords:** undergraduate research, CURE, Computer Science.

## 1. INTRODUCTION

CUREs trace their roots to the broader movement toward active learning and student-centered education. While traditional lecture-based courses dominated higher education for centuries, educators recognized the need for more engaging and experiential approaches. Undergraduate Research Experiences (UREs) in general, and CUREs specifically, emerged as a response to this demand. The original focus was in the Biological Sciences and Chemistry, but has expanded to other disciplines (Wei & Woodin, 2011).

Undergraduate Research Experiences are different from traditional labs, where students expect step-by-step instructions and expected results are known. While traditional labs are designed to reinforce or verify content taught in lectures, UREs focus on authentic research and explore open-ended questions. UREs are also less prescriptive and allow students to explore, design experiments, and make discoveries. The research questions are broader, often interdisciplinary, and align with ongoing research. Students are encouraged to be independent, think critically, and use their creativity. While the focus in traditional labs is on following instructions and grading, UREs promote strong mentoring relationships with faculty (Holmes, 2020).

This paper describes the concept of URE and CUREs, a repository of projects supported by the National Science Foundation, development of the first authentic CS CURE in this repository, and result of a student survey in the class where it was offered.

## 2. LITERATURE REVIEW

### History of undergraduate research

Undergraduate research, often described as the exploration of a specific research topic by

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undergraduate students seeking to make original contributions to their disciplines (Council on Undergraduate Research, 2024b), has roots in the 19th and 20th centuries. Its origins trace back to early practices in Germany where Wilhelm von Humboldt founded the University of Berlin in 1810, establishing a model for undergraduate research. By the early 1900s mentions of undergraduate research appeared in journals and magazines and in 1912 the University of Chicago established the undergraduate research prize in memory of Howard Ricketts. Since then, many universities and colleges worldwide have instituted programs to foster research at the undergraduate level. The concept gained prominence with the creation of MIT's undergraduate research opportunities program (UROP) (Massachusetts Institute of Technology, 2024) in 1969 which led to an explosion in popularity. The Council on Undergraduate Research (CUR) was established in 1978, the National Conference on Undergraduate Research (NCUR) was formed in 1987, and both have merged in 2010 (Council on Undergraduate Research, 2024a).

**Type of undergraduate research**

UREs are independent research projects, where students work one-on-one with faculty members on their own research or joint projects with faculty. They can be structured as research assistantships, where students assist faculty with their ongoing research, involving things like lab work, data analysis, and data collection; independent student research guided by faculty, often as honors projects or senior theses; and summer research programs, often supported by the National Science Foundation (National Science Foundation, 2024). Undergraduate research can now also be offered within courses as CUREs, which will be discussed later.

**Benefits of undergraduate research**

UREs have many benefits, including providing students with research skill training (Brownell et al., 2015; Cartrette & Melroe-Lehrman, 2012; Cuthbert et al., 2012; Szteinberg & Weaver, 2013); development of student skills like analytical, intrapersonal, and interpersonal skills (Adedokun et al., 2012; Brownell et al., 2015; Cartrette & Melroe-Lehrman, 2012; Cuthbert et al., 2012; Hudley et al., 2017; Laursen et al., 2010; Park & Kerr, 1990).

Another benefit is retention and education continuation (Adedokun et al., 2012; Gentile et al., 2017; Hanauer et al., 2012; Hernandez et al., 2018). Despite high interest of students in STEM disciplines due to high demand and attractive salaries, only 40% of the students who enter a STEM undergraduate program earn a STEM degree (Seymour & Hunter, 2019). These numbers are even lower for minority students. Previous studies report that 68% of students show more interest in STEM careers after participation in undergraduate research (Graham et al., 2013; Russell et al., 2007) including continuing to a graduate degree (Zhan, 2014). Students are also more likely to graduate in a STEM field (Gentile et al., 2017; Hernandez et al., 2018; Ing et al., 2021). It is clear that UREs are one of the high-impact measures to increase STEM retention (Denton & Kulesza, 2024; Gentile et al., 2017; Russell et al., 2007).

Broad availability of research opportunities is also an issue of equity. Making research available to all students includes historical minority groups (Gentile et al., 2017), which might otherwise not participate. More diversity in research increases the number of points of view (Bangera & Brownell, 2014).

Students are not the only ones to benefit from undergraduate research. Faculty benefit from closer integration of teaching and research, positive influence on promotion and tenure, publication of research in both scientific and education journals, and more fulfillment in teaching itself (Fukami, 2013; Kowalski et al., 2016; Shortlidge et al., 2016).

**The call for more undergraduate research**

Since the start of this century, many have called for changes in undergraduate research to increase student interest in research (Botstein, 2000; Brewer & Smith, 2011; National Research Council, 2003; Obama, 2013; President's Council of Advisors on Science and Technology, 2010, 2012). One response to this call has been to create CUREs, which are offered within courses, so that all students in the course can participate (Auchincloss et al., 2014).

**CUREs**

CURES have gained prominence in higher education as equitable alternatives to traditional UREs. These learning experiences involve whole classes of students addressing research questions or problems with unknown outcomes, engaging in scientific practices, and collaborating extensively. There is now a growing consensus about the nature of CUREs. Auchincloss et al. (2014) mention five characteristics: 1) students learn scientific practices; 2) there is an element of discovery, so that students work with novel data; 3) topics are broadly relevant, could potentially be published, and may be of interest to the larger

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community; 4) students engage in a high level of collaboration; and 5) Iteration is built into the project, so students can learn through repetition.

An analysis of features of CUREs in biosciences showed that students experience (1) the scientific process, (2) the technical aspects of science, (3) the professional development associated with research, and (4) building scientific identity (Burmeister et al., 2023). Within the CURE movement, more resources now become available.

**Resources for instructors**
In 2012, CUREnet was established with support from the NSF (National Science Foundation, 2011) and expanded to CUREnet2 in 2017 (National Science Foundation, 2017). The goal is to engage a broad group of institutions, faculty, and students in CUREs into their science laboratory courses which allow students to actively participate in research projects within the classroom setting. It maintains a website at https://serc.carleton.edu/curenet/index.html (Science Education Resource Center, 2017).

| Discipline | # |
|---|---|
| Life Sciences (Biology, Biochemistry, etc.) | 41 |
| Chemistry | 16 |
| Environmental Science | 10 |
| Computer Science | 5 |
| Geoscience | 4 |
| Statistics | 4 |
| Engineering | 2 |
| Physics | 2 |
| Social Sciences | 2 |

Table 1 - CUREs on CUREnet

| Discipline | # |
|---|---|
| Biology | 34 |
| Biochemistry | 7 |
| Chemistry | 6 |
| Engineering | 3 |
| Physiology | 2 |
| General STEM | 2 |
| Food Science | 2 |
| Biotechnology | 1 |
| Geoscience | 1 |
| Computer Science | 1 |
| Environmental Science | 1 |
| Astronomy | 1 |
| General | 1 |
| Psychology (non-STEM) | 3 |
| Social Sciences (non-STEM) | 2 |

Table 2 - published CURE studies

Currently, 57 CUREs have been published, many within multiple disciplines. Computer Science is mentioned five times, but all are support for another primary discipline (Table 1). Most are in Biology, Biochemistry, and Chemistry. This is consistent with Amad and Al-Thani (2022), who reported that out of 67 academic studies involving CUREs, 47 were from these three disciplines and 12 other disciplines shared the remaining 20 (Table 2). Computer Science only accounted for one. That does not mean that other disciplines are not interested. Even Mathematics may be interested in using CUREs. Deka et al. (2023) proposed a specific Mathematics CURE model.

**Measuring CUREs effects**
Student persistence, the continued pursuit of STEM degree and career, is a critical metric in science education research. Some studies measure the effectiveness of CUREs with completion of a science, technology, engineering, or mathematics (STEM) degree or advancing to a graduate program (Corwin et al., 2015). This is a very broad measurement, which takes a lot of time to measure. Hanauer et al. (Hanauer et al., 2016) addressed this concern by introducing the Persistence in the Sciences (PITS) scale, a novel instrument designed to assess how much CUREs influence students' decisions to remain in STEM fields. The PITS scale is an experimentally validated 39 question survey designed to determine student perceptions in six themes deemed predictive of continuing in a STEM discipline. The six sections on the PITS include Project Ownership-Content, Project Ownership-Emotion, Science Self Efficacy, Science Identity, Scientific Community Values, and Networking (Figure 1).

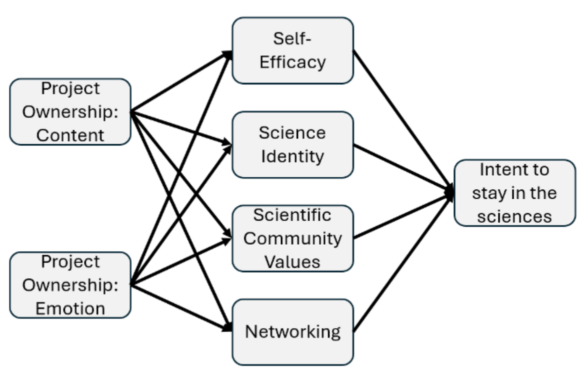


Figure 1 - PITS model

Project Ownership assesses how much a student feels connected to their research project, both emotionally and in terms of content. Self-Efficacy measures a student's belief in their ability to

 

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succeed in scientific endeavors. Science Identity assesses how strongly a student identifies with the role of a scientist and the scientific community. Scientific Community Values measures a student's alignment with the values and norms of the scientific community. Networking assesses a student's ability to build relationships and connect with others in the scientific community.

PITS has been shown to be an effective tool for evaluating undergraduate research’s influence on retention (Hanauer et al., 2017, 2018, 2022). It has been validated with a Cronbach’s Alpha of 0.94 (Allison et al., 2022) and has also been validated in Cole at al.(2021). The networking subscale has been validated in Hanauer (2015). A listing of the questions in the PITS scale, as used for this study, is included as Appendix A.

## 3. METHODOLOGY

Since PITS can be used to measure retention in STEM, we tried to use the model in PITS to demonstrate intent to continue in a STEM discipline.

This study was performed in our introductory programming class. The class consists of a three hours lecture and one-hour lab for a total of four credit hours. During the semester, students complete 6 programming assignments and have one final exam in multiple choice format. In the past, since typing skills were considered a critical success factor for computer programming, students would also practice a substantial number of hours typing computer code as homework. When generative AI capable of writing computer code appeared, this clearly was no longer the case. The typing homework was replaced with a semester long research project related to using generative AI in introductory programming classes. The research report was due at the end of the semester and the material was presented to the class throughout the semester. The Blackboard website for the course contained all necessary materials, including two ISCAP publications, one on using generative AI for programming and the other on appropriate uses of generative AI in general.

Students could formulate their own research questions. To help them get started, they had three suggestions. The first suggestion was to compare generative AI engines for use in the class. The suggested research design was an experimental design that could be analyzed in Excel. The second suggestion was using a focus group or survey about appropriate uses of generative AI in the class, and the third suggestion was surveying student perceptions about using AI for programming. After the students submitted the research report, a link opened to the survey about the research project. Thus, only students who completed the research report could participate in the survey. The survey was for potential extra credit in the class if 80% of the students completed the survey.

The survey consisted of 36 items of the PITS scale in Likert format ranging from strongly agree to strongly disagree. In addition, two questions were added about the likelihood of graduation in a stem discipline and how much this research experience might have influenced that decision. Both were in numerical format. Finally, students could complete one open-ended question comparing the course with the research experience with a similar course without it. The questions are included in Appendix A.

## 4. SAMPLE AND DATA COLLECTION

Traditionally the class is a mix of majors, non-majors, and undeclared students. Enrollment in the class was 30 at the beginning of the semester, and three students withdrew during the semester. Demographics of the class are listed in Table 3.

| | |
|---|---|
| Male | 23 |
| Female | 4 |
| Freshman | 7 |
| Sophomore | 8 |
| Junior | 9 |
| Senior | 1 |
| Post-grad | 2 |
| CS major | 6 |
| Non-major | 15 |
| Undeclared | 6 |

Table 3 - Demographics

Of the 27 students who finished the course, 19 submitted the research report. Fourteen students completed the survey, and since this fell below the 80% threshold, no extra credit was awarded.

## 5. ANALYSIS AND FINDINGS

After the semester was over and final grades had been awarded, the results were imported to an

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Excel spreadsheet. First, the Likert scores were replaced with numerical scores, with 1 for strongly disagree and 5 for strongly agree. Next, 5 missing answers out of a total of 532 answers were replaced with the mean of the other answers for that particular question. Since the PITS survey has been validated as having six factors, the average score for each factor was used for analysis. The outcome score was calculated as the product of likelihood of continuing in STEM with the relative contribution of the research project. In other words, if a student was 100% certain about continuing in STEM but the project had 0% contribution, we used a 0% score. Likewise, if a student was 80% certain and the relative contribution to that decision was 70%, we used the 56% outcome.

With the factor scores for each factor and the composite outcome score, each path was checked for statistically significant relationships with linear regression. A common rule of thumb for Structural Equation Modeling (SEM) is having at least 10-20 times as many observations as variables. For 39 questions, this would suggest a minimum of 390 to 780 responses. Since the PITS scale has been validated with SEM, it is appropriate to use the factor structure identified in SEM by using the factor scores as predictors in the regression analysis. Table 4 lists the paths, their coefficient, and the statistical significance.

| Path | Coeff. | Sign. |
|---|---|---|
| Content to self-efficacy | 0.82 | 0.12 |
| Emotions to self-efficacy | 0.38 | 0.11 |
| Content to science identity | 0.86 | 0.19 |
| Emotions to science identity | 0.41 | 0.16 |
| Content to community values | 0.45 | 0.33 |
| Emotions to community values | -0.01 | 0.96 |
| Content to networking | 1.10 | 0.05 * |
| Emotions to networking | 0.36 | 0.17 |
| Self-efficacy to effect | 0.27 | 0.05 * |
| Identity to effect | 0.07 | 0.53 |
| Community to effect | -0.08 | 0.63 |
| Networking to effect | 0.08 | 0.56 |

Table 4 - Paths

The table shows that only two relationships had statistical significance. Since content and networking on one hand, and self-efficacy to effect of the project on the other do not follow each other, it is not clear how this should be interpreted. Based on the results in this computer science course so far there is no discernible effect of this CURE on recruitment and retention in the major.

The responses to the essay question were more encouraging. We used sentiment analysis with TextBlob in Python for preference for courses with or without a CURE. TextBlob is an effective tool to analyze sentiment (Hazarika, 2020). The Python code, individual answers, and their scores are listed in Appendix B. Using binomial distribution, the probability of 11 of 14 students preferring the CURE course was statistically significant at 0.02.

## 6. CONCLUSIONS AND RECOMMENDATIONS

Course-based undergraduate research experiences are virtually unknown within the field of computer science. This is surprising since many computer science majors like to work on their own projects. Other undergraduate research experiences, not course based, are frequently used. Examples are Research Experiences for Undergraduates (REUs) sponsored by the NSF, and state research days and university research days where students can show poster presentations of their research.

Perhaps one reason for the lack of CUREs in computer science is the lack of tradition. Disciplines like biology and chemistry include a lot of labs, and faculty in those disciplines have progressed from prescriptive exercises to more research-based projects. In Computer Science, labs are typically used in lower-level courses and are highly structured, not leading to problem solving and independent thinking. To combat students' impressions that this is just another lab experience, creating CUREs specifically for computer science and posting them in the CUREnet collection may provide instant credibility.

The findings of the survey are mixed. The qualitative part indicated preference for using CUREs, but the quantitative part did not. The number of students in the study is small, the response rate was around 50%, so the study bears repeating in CS courses. In the semester after this study, we have included CUREs in the Software Engineering and Software Testing courses.

Faculty who are interested in incorporating this CURE in one of their classes, can find a direct link to all materials at https://serc.carleton.edu/curenet/collection/284384.html . For faculty who are interested in developing their own CURE, we recommend reviewing the submission page for CUREs at https://serc.carleton.edu/curenet/contribute_CURE.html . Going through this process involves defining Student Goals and Research Goals, Assessment materials, and planning for staffing, among others. An account is necessary but free.

While the specific student research experiences on CUREnet are only of use in other disciplines, their use has proven beneficial in student recruitment and retention in the major. CS faculty have an opportunity to use the model within Computer Science, and get similar results.

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## Appendix A – Survey questions (adapted from Hanauer et al., 2016)

**Project Ownership: Content**
1. My research will help to solve a problem in the world.
2. My findings were important to the scientific community.
3. I faced challenges that I managed to overcome in completing my research project.
4. I was responsible for the outcomes of my research.
5. The findings of my research project gave me a sense of personal achievement.
6. I had a personal reason for choosing the research project I worked on.
7. The research question I worked on was important to me.
8. In conducting my research project, I actively sought advice and assistance.
9. My research project was interesting.
10. My research project was exciting.

**Project Ownership: Emotion**
1. Your emotion after this project: Delighted.
2. Your emotion after this project: Happy.
3. Your emotion after this project: Joyful.
4. Your emotion after this project: Amazed.
5. Your emotion after this project: Surprised.
6. Your emotion after this project: Astonished.

**Self-Efficacy**
1. I am confident that I can use technical science skills (use of tools, instruments and techniques)
2. I am confident that I can generate a research question to answer.
3. I am confident that I can figure out what data / observations to collect and how to collect them.
4. I am confident that I can create explanations for the results of the study.
5. I am confident that I can use scientific literature and reports to guide my research.
6. I am confident that I can develop theories (integrate and coordinate results from multiple studies)

**Science Identity**
1. I have a strong sense of belonging to the community of scientists.
2. I derive great personal satisfaction from working on a team that is doing important research.
3. I have come to think of myself as a 'scientist'.
4. I feel like I belong in the field of science.
5. The daily work of a scientist is appealing to me.

**Scientific Community Values**
Check the answer that best reflects how much the person in the description is like you:
1. A person who thinks discussing new theories and ideas between scientists is important.
2. A person who thinks it is valuable to conduct research that builds the world's scientific knowledge.
3. A person who thinks that scientific research can solve many of today's world challenges.
4. A person who feels discovering something new in the sciences is thrilling.

**Networking**
I have discussed my research in this course with my parents (or guardian)
I have discussed my research in this course with my friends.
I have discussed my research in this course with students who are not in my class, but in my institution.
I have discussed my research with students who are not at my institution.
I have discussed my research in this course with professors other than my course instructor.

**Intent to persist**
How likely will you be to graduate in one of the STEM disciplines (Science, Technology, Engineering and Mathematics) ?
1 100% 2 90% 3 80% 4 70% 5 60% 6 50% 7 40% 8 30% 9 20% 10 10% 11 0%
How much has this research experience influenced that decision?
1 100% 2 90% 3 80% 4 70% 5 60% 6 50% 7 40% 8 30% 9 20% 10 10% 11 0%

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**Appendix B – Open Ended Question Responses**

**Python code**

```
from textblob import TextBlob

text = "I have not had a similar course research project. The closest comparison is for a research topic for a final, but this was much more personal and allowed for more creative freedom. "
blob = TextBlob(text)

# Get the sentiment polarity
polarity = blob.sentiment.polarity

# Determine sentiment
if polarity > 0:
 sentiment = "1"
elif polarity < 0:
 sentiment = "-1"
else:
 sentiment = "0"

print(f"Sentiment: {sentiment}")
```

| Student Comment | sentiment |
|---|---|
| I have not had a similar course research project. The closest comparison is for a research topic for a final, but this was much more personal and allowed for more creative freedom. | 1 |
| I have not had another course that is similar to this one but I would say that the research project at the end of the semester is very beneficial. You can learn over the ocurse of the semester, but I feel like its just scratching the suface. With the research project, you get to dive deep into the class and discover some things that may have not known about. It really lets you get a sense of why you took the class and what to look forward to if you were to take another class just like this one or even pursue this degree. | 1 |
| I thoroughly enjoyed this course. At first it was difficult to keep up, but (instructor's name removed for review) made it easy to understand all the course work material. He always made sure we understood the contentand didn't ridicule us for not knowing the answers but instead using it as a teaching opportunity for the students. | 1 |
| I would compare this course with a similar course without a reaserch project by this course being more enguaging. | 1 |
| im not sure i havent had any other courses simliar course yet because this is still my first year here | -1 |
| I can definitely say this course compares to my introduction to information security because it's similar in how much work I got to get done in the course. | 1 |
| I think this course focuses more on the cultivation of research thinking rather than just learning knowledge itself, although knowledge is also very important. | 1 |
| It has taught me some valuable lessons that I wouldn't have known if there weren't a research question involved. One of the most significant lessons I've learned is the importance of curiosity and inquiry. Research questions prompt us to delve deeper into topics, encouraging us to ask why and how things work, leading to a deeper understanding. Additionally, research teaches patience and perseverance. It's not always easy to find answers, and sometimes we encounter dead ends or unexpected results. However, these challenges cultivate resilience and problem-solving skills. Moreover, research fosters critical thinking and analytical skills. By evaluating sources, synthesizing information, and drawing conclusions, we become more adept at discerning facts from opinions and making informed decisions. Ultimately, research is not just about finding answers; it's about the journey of discovery and the personal growth it entails. | 1 |
| It felt about the same as a usual end of semester project, however this one felt like it mattered more than just a grade because I knew other people may see it, however | 1 |

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| | |
|---|---|
| unlikely. Furthermore, I had a lot of fun knowing it is built to be an actual research project. I will be attending graduate school eventually and it was nice to get a taste of that type of research. | |
| This course would not have been as engaging without the research project. Comparing this course with the research project and a course without one, I believe I would have been less engaged with the course material in a class without a research project. Having this project made me enagage and dive deeper into the course material and gather a deeper understanding on my own. | 1 |
| Almost the same. The research project was a very small part of the class. | -1 |
| My eletrical enginering course made me think hard just like this class! | -1 |
| More challenging toward the end of the semester | 1 |
| A class with a research project gives me the opportunity to apply things I have learned, gain a better understanding, and it allows further research opportunities. A class without a research project would probably focus more on basic knowledge and building skills without experimenting with resources. | 1 |
| | |
| Binomial distribution: =BINOM.DIST(11,14,0.5, FALSE) | 0.022 |