

Course-Based Undergraduate Research Experiences as a Community of Practice (CoP)

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ABSTRACT: Course-based Undergraduate Research Experiences (CUREs) are a pedagogical model where a traditional undergraduate course is transformed into a research-intensive course, offering an alternative pathway to research for undergraduate students. Given the novel learning context of CUREs, there is a need to understand the learning that occurs and the impact of social interactions on students in defining and managing the socially negotiated understandings and practices of the science research laboratory. This manuscript reports the findings from a qualitative study of students enrolled in a CURE sequence that bridged a lower-division organic chemistry laboratory with an upper-division quantitative analysis laboratory. Communities of practice are groups of people who share a common objective or seek to address a common problem, characterized by three elements, domain, community, and practice. The design elements identified for CUREs, research practices, discovery, relevance, collaboration, and iteration, can be aligned with the three elements of CoP to provide a lens to make sense of the learning that occurs in this novel context. Focus groups consisting of 3–5 students each were conducted with students participating in two cohorts ($N = 65$) of the CURE sequence during the last week of the academic term. In addition, semistructured interviews were conducted with CURE faculty. Thematic analysis of the interview data derived three themes: *working toward a common goal*, *addressing obstacles*, and *developing a deeper understanding of the science content*. The alignment of the themes with the Lave and Wenger's Community of Practice (CoP) Framework is described and provides the basis for applying CoP to research on CUREs.

KEYWORDS: Second-Year Undergraduate, Upper-Division Undergraduate, Analytical Chemistry, Organic Chemistry, Inquiry-Based, Discovery Learning, Undergraduate Research, Chemical Education Research



INTRODUCTION

Undergraduate research experiences (UREs) are an effective tool for enhancing the undergraduate experience, while also boasting a wide-array of institutional benefits, however there are limited opportunities and numerous barriers for undergraduate students to participate.^{1,2} Course-based Undergraduate Research Experiences (CUREs), a pedagogical model where a traditional undergraduate course is transformed into a research-intensive course, offer an alternative pathway to research that expands access and removes barriers to research for undergraduate students.^{1,3}

UREs have been shown to increase interest in a career in STEM, promote diverse career pathways for marginalized groups, and increase the enrollment in graduate education among minoritized students.^{4–6} UREs offer a potential solution to the problems facing retention of students in STEM related majors, however participation can be constrained by faculty laboratory space, student intimidation by an application and selection process, low student awareness of possible research opportunities, limited monetary support from the university, and research often being an elective credit.^{1,7} All of these have a

greater impact on marginalized groups and first-generation students, reducing the overall diversity of those applying to UREs.^{8–10}

These barriers to undergraduate research are alleviated by embedding research directly into the curriculum as a CURE. The five elements that have been recommended for CURE design are research practices, discovery, relevance, collaboration, and iteration.³ CUREs engage students in a relevant discovery-based scientific work, where they can develop scientific practices through collaboration with peers through iteration and evaluation of work within a research context.³ CUREs have the potential to provide faculty a setting to connect teaching and research,¹¹ with potential added benefits such as increased

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research productivity, publications, and recruitment of students into research.¹²

We have previously published the design and implementation of the CURE sequence, i.e., research related CUREs that span more than one semester, as well as the results from a comparison of CURE students with students enrolled in traditional laboratories.^{13,14} This manuscript presents qualitative data from focus groups with students and semistructured interviews with CURE faculty that provides insight into their experience with the CURE sequence.

THEORETICAL FRAMEWORK

The apprenticeship model for teaching or training that has been used historically for passing down knowledge and skills, from an expert to a novice,¹⁵ is an accurate representation of how students currently participate in research at the undergraduate level.^{2,16,17} Typically, a student is taken in by a professor to learn and develop research skills as they progress toward a undergraduate or graduate degree. Situated cognition is a theory founded on the assumption that engaging in social practices are the fundamental process by which individuals learn. The notion of situated learning requires an understanding of the role of interactive learning in defining and managing the socially negotiated understandings and practices of a particular context.¹⁸ Given the novel learning context of course-based undergraduate research experiences there is a need to understand the learning that occurs and the impact of social interactions on students in defining and managing the socially negotiated understandings and practices of the science research laboratory. In their initial ethnographic work on trades, e.g., midwife, butcher, tailors, Lave and Wenger characterized this learning through participation as a *Community of Practice*.¹⁹ Lea²⁰ argues that researchers in higher education should revisit the early work of Lave and Wenger “to explore the value of understanding learning through this lens” (ref 20, p. 194). In higher education, the concept of CoP is more often introduced as an educational model in a top-down manner with the goal of turning a disjointed group into a “community”. Research demonstrates that communities of practice build professional and personal links both within and across faculty, student services, and administrative and support units.²¹ Indeed, multiple communities of practice have been identified in postsecondary contexts at the administrative or faculty level: undergraduate mathematics lecturers, student-staff across universities, graduate students, and physics faculty.^{21–25} Recently, chemistry education researchers have applied a CoP framework to student organizations participating in outreach.^{26,27} This work represents a rare example of the CoP framework being used to describe a situated learning context that includes faculty, graduate students, and undergraduate students.

The term community of practice or CoP was conceptualized to describe a social learning system and is characterized by three core elements. The first, *domain*, is defined as a shared common passion or concern; the second, *community*, is a commitment to a specific domain and a shared competence pertaining to that passion; and the third, *practice*, is a shared repertoire of tools, processes, and resources.²⁸ The integration of the three elements, domain, community, and practice, have the potential to bring a CoP into existence. The design elements identified for CUREs, research practices, discovery, relevance, collaboration, and iteration can be aligned with the three elements of CoP, with domain identified as the CURE itself, community built through

the collaboration, and practice developed through the research experience. Returning to the apprenticeship model, it is important to remember that the research is conducted at the side of an expert such as faculty, or an advanced trainee or graduate researcher. This distinguishes the CURE setting from other collaborative instructional models. A situated learning theory, Communities of Practice (CoP), was adopted to explore the group evolution of student and faculty researchers within a CURE. This study was therefore guided by the research question: What elements of a Course-based Undergraduate Research Experience allow development of a Community of Practice for undergraduate students and faculty?

METHODOLOGY

Context

This project takes place at a large, primarily residential, four-year, high research activity, doctoral university, R2 designation per Carnegie Classification.²⁹ The CURE sequence developed out of a collaborative project between an organic chemist (William E. Allen) and an analytical chemist (Anthony M. Kennedy) examining trehalose as a possible preservative for human red blood cells. Organisms with naturally high concentrations of trehalose in their tissues tend to thrive in unusually harsh environments—extreme cold, the driest deserts, even the vacuum of space. The preservative character of trehalose is believed to arise from its ability to lodge within cell membranes and displace water molecules.^{30–33} By varying the carbon chain length between trehalose and an aromatic anchor, the researchers hypothesized that the depth of membrane penetration could be controlled, perhaps leading to preservatives that would be effective at low concentrations and suitable for clinical use with human red blood cells. The organic chemist was working on synthesis of potential trehalose variants, which would then be analyzed for membrane penetration by the analytical chemist. Both projects had the potential to run as a CURE and the linked project was serendipitous opportunity to bridge two laboratory courses, Organic II and Quantitative Analysis (Analytical). Both courses were designed to align with the five elements of a CURE—research practices, discovery, relevance, collaboration, and iteration—that have been recommended for CURE design.³ This alignment between the CUREs and the five components are presented in Table 1.

Organic CURE

The Organic CURE was designed to meet the learning outcomes for the conventional organic chemistry II laboratory course, through synthesis of new compounds. Published synthetic procedures were adapted for this project.³⁴ In order to allow the organic reactions to reflux overnight, maintain the dedicated instrumentation, and specialized equipment, it was necessary to have a dedicated research space for the CUREs. The department identified an underutilized laboratory that could be setup as an enhanced teaching lab dedicated to research-based courses. The facility has 6 workstations that accommodate up to 4 students each with the necessary glassware for conducting the research. There is a center bench for instrumentation and a bench along the back wall with 2 rotary evaporators and a lyophilizer. The instrumentation includes a high-performance liquid chromatography, a fluorimeter, infrared spectrometer, UV–vis, and a differential scanning calorimeter.

The class was divided into groups comprised of 3–4 students. Target molecules synthesized by the groups differed by the

Table 1. Alignment of the Organic and Analytical Research with the CURE Elements

CURE Elements	Organic CURE	Analytical CURE
Research Practices	Synthesis design and execution, mass spec, HPLC, and NMR analysis of compounds.	Lipid preparation, differential scanning calorimetry, fluorescence, UV-absorption, and infrared spectroscopy.
Discovery	Synthesize two new compounds; adaptation of procedure required.	Conducting instrumental analysis on new compounds with unpredictable outcomes.
Relevance	Students were most often drawn to select the course based on a desire to work on the overarching problem: "How do we preserve blood for more than 42 days?"	
Collaboration	Students worked in teams of 3–4 and considered results between teams.	Students worked in teams of 3 and focused on a specific instrumental analysis.
Iteration	Teams made changes to methods and repeated syntheses.	

number of intervening $-\text{CH}_2-$ groups linking the trehalose (e.g., zero, one, three, six, or nine) or the orientation of the carbon chains on an aromatic ring (e.g., ortho and para). Students were responsible for all aspects of the synthesis, purification, and characterization of new molecules. Thus, all members of the CURE sections gained experience in reaction design, extraction, thin-layer chromatography (TLC), high performance liquid chromatography (HPLC), mass spectrometry (MS), and proton nuclear magnetic resonance (NMR).

Analytical CURE

The Analytical CURE was designed to meet the learning outcomes for conventional analytical chemistry laboratory course through bioanalytical/biophysical chemistry research. For the Analytical CURE the planned modules were differential scanning calorimetry (DSC), ultraviolet–visible spectroscopy (UV–vis) absorption, and infrared spectroscopy (IR). It was initially expected that each group would use a sugar prepared from the organic course, however not all groups completed the synthesis and had to work with other sugars provided by the lab instructor (i.e., maltose). It was also anticipated that each group would spend approximately 3 weeks each on four modules and that they would rotate through each. It was clear early in the project that this plan was overly ambitious, and students spent the semester using one or two of the techniques while also being briefly exposed to the other techniques.

Student Participants

The CURE sequence followed the recommended curriculum structure, Organic II Laboratory in the Spring and Quantitative Analysis in the Fall. This study was approved by the University Internal Review Board (16002076) and consent was obtained from all participants. It was a goal of the study that student demographics of those participating in the CURE sequence was representative of the general population of students at the university. To this end, participants were recruited from a pool of ($N = 307$) students enrolled in the Organic I lecture course. All students were given an informational flyer with a portion to indicate interest in the CURE (yes or no) and to provide identifying information. The CURE participants were selected from the "yes" group ($N = 177$) using matched sampling based on four parameters: year, major, gender, and URM status. The students in the organic CURE continued to the second semester of the sequence, the analytical CURE. The analysis of the student demographics, previously published,¹³ established that there was not a significant difference between the CURE students and the eligible population with respect to binary gender (collected as female/male), URM status (defined as

students that identified as Black, Hispanic, Native American, or two or more races), GPA, or major ([Supporting Information](#) for chi-squared tables).

Focus Group Interviews

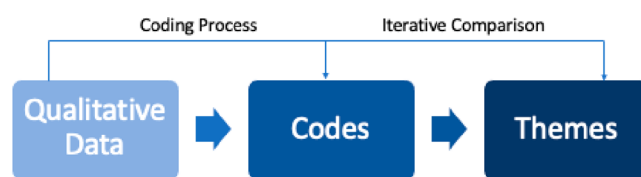
Focus groups of 3–5 students ($N = 65$) were formed with students from separate research groups, so a student would not feel hesitant in giving a response in front of peers. Focus group discussions were held at the end of each academic semester, spring for Organic and fall for Analytical. The questions used ([Supporting Information](#)) were developed to capture elements of the CURE that students may have experienced.³⁵ A total of 15 focus groups averaging an hour in length were transcribed.

Faculty Interviews

Each of the faculty researchers were interviewed by the external evaluator for the project. The interviews took place after the semester had ended and grades were submitted. Faculty were provided a set of questions developed from the literature^{12,36} ([Supporting Information](#)) and a semistructured interview protocol was used to explore their experiences in designing and implementing a research-based laboratory course. The interviews were transcribed, and member checked by the interviewees. Faculty interviews were used to check the student interviews and substantiate codes and themes that emerged from the student focus groups.

Coding and Thematic Analysis

The process of Thematic Analysis, illustrated in [Figure 1](#), was used in this study to identify themes that would reflect detailed

**Figure 1.** A simplified model of thematic analysis used in this study.

information on the student's research experiences from within the CURE sequence.^{37,38} Themes are patterns of meaning across all data items that can be umbrellaed under a central concept.³⁹ Deductive coding was used based on three established codes (collaboration, encountering obstacles, and project ownership) from the literature⁴⁰ as well as the five CURE elements.³ Through iterative analysis of the transcripts, additional codes were added. Using a transcript from the Organic Spring 2019 focus group BW and LS established a codebook describing how

Table 2. Codes and Definitions

Code	Definition
Collaboration I ^a	Participants work toward achieving a common goal as a collective.
Discovery ^b	Participants have the opportunity to generate new scientific knowledge.
Relevance ^b	Participants work is of interest to a community beyond the classroom.
Iteration ^b	Participants have opportunities to revise or repeat aspects of their work to fix problems, improve validity of their results.
Confidence	Participants develop the ability to become certain about how to use a certain technique or instrument over time.
Encountering Obstacles ^a	Participants address unexpected results and adapt their synthetic methods, product recovery, data analysis, or sample preparation.
Project Ownership ^a	Participants take pride in the research and feel driven to accomplish goals.
Research	Participants understand how research is conducted and the related challenges.
Collaboration II ^a	Participants work together, help each other, build off one another's work, and provide and respond to feedback.
Learning	Participants develop a deeper understanding of the relevant course content.

^aPublished codes.²⁶ ^bCURE Elements.³

Table 3. Theme and Corresponding Codes

Theme	Codes
Working toward a Common Goal	Collaboration I Research Relevance
Addressing Obstacles	Encountering Obstacles Iteration Collaboration II
Understanding of Science Content	Discovery Learning Project Ownership Confidence

each code from the literature applied to these CUREs after consulting a transcript of one focus group. These two coders coded one transcript and resolved differences in interpretation, revising the codebook as needed. The remaining transcriptions were coded by consensus.

The codes with their definitions are presented in Table 2. Note that there are two codes for collaboration, where *collaboration I* identified instances where students discussed

working toward the broader goal of finding a blood preservative and *collaboration II* identified groups working together within and between the smaller groups. Once coding was completed, the established codes were analyzed, and common patterns were identified as themes. Each theme included a group of codes that related to the broader story of the student experience within the CURE sequence. After the themes were developed, they were reviewed by other lab members and the principal investigator to confirm representation of the interview data.

Each of the three themes (Table 3) offer a distinct story relating to the research experiences that students encountered while participating in the CURE sequence.

RESULTS AND DISCUSSION

In the following paragraphs, we discuss the alignment of the codes with each of the three themes using exemplars from the focus groups and faculty interviews. Exemplars for each code from both students and faculty are provided to illustrate the alignment of the novice and the expert experiences (Tables 4, 5, and 6). In order to answer the research question, we then present the alignment of the themes and code with the community of practice elements of domain, community, and practice (Table 7).

Table 4. Working toward a Common Goal: Student and Faculty Exemplars

Code	Student Exemplars	Faculty Exemplars
Collaboration I	And that point of broader impact is what is key to a CURE. So in terms of CUREs, like I was saying, it is got to be collaborative because that is how research is done. And also, the teamwork aspect—the group dynamic really mattered. And everyone was working toward the same goal, so it was just nice.	And that is I want them to feel like we're all part of a research group, like we're all a team. It is us against the world. Go team! [Organic] He [WA] came in to look at two-sets of very unusual data that we really could not explain. He had a completely different take on it that changed the direction of the research. It was a big step forward for that project in understanding their data and designing new experiments. Students could see truly how collaboration happens. [Analytical]
Research	I was like, well, I just want to see what it is because I did not really want to do research that much. But it would have been interesting just to see, and it was going to count as credit, and stuff like that. So, I tried it, and I really enjoyed it because it was not the cookie-cutter type situation because I do not really think that those are applicable to people that want to do that in their field because they are not going to be able to problem-solve very well.	This is their first research experience. The wonderful thing this class does is it shows them they do not have to be perfect, real people do this every day, there is no gene you have to have. It brings confidence and long-range thinking of continuing in research. And I know for a fact so many of these students would never, ever have stepped foot in a research lab without this opportunity. [Organic] We had difficulty with solubility. Research become much more exploratory, had to work to keep the students motivated, they saw it as failure for the first few weeks. Students were very concerned about grades, so had to keep them focused and motivated with the notion that "this is research". [Analytical]
Relevance	So, if we could use trehalose to preserve cells at freezing temperature, that in itself would save thousands of lives. That means that the donated blood will have a longer shelf life.	Initially, the issue was grade, but toward the end they were disappointed that they did not answer the question they set-out to answer—which was a blood preservative. Naive conceptions of what's involved. [Analytical]

Table 5. Addressing Obstacles: Student and Faculty Exemplars

Code	Student Exemplars	Faculty Exemplars
Encountering Obstacles	In my group, we did fluorescence data, for example, and we should have seen a linear relationship, like a direct relationship between our molecule and our emission, but it was an inverse relationship.	It was clear early in this semester that this plan was overly ambitious, and students spent the entire semester predominantly using one or two of the techniques while also being briefly exposed to the other techniques. [Analytical]
Iteration	So, the next time, we made sure to put it in as soon as possible. And there was another one where he changed—it was like one—I do not remember which reaction it was. But he had to change the catalyst we used, because the first one just did not work.	This change [only one or two techniques] was dictated by the students who worked to pull everything possible out of the data that they then used in designing follow-up experiments. [Analytical]
Collaboration II	I mean, sure, some laboratories are like that. But it is not like all laboratories are like that. And especially here, it was very collaborative. You are encouraged to ask people for help, work with other groups, ask people what they did for their reaction.	The laughter and the camaraderie, the fact that each group of 3 works as a living, breathing research group. Watching the groups is inspiring. [Organic]

Table 6. Understanding of Science Content: Student and Faculty Exemplars

Code	Student Exemplars	Faculty Exemplars
Discovery	I think a big thing was extraction. I came in to organic two lab—we'd done it in organic one lab. But I got into organic two lab. It was like, what is this, and why do we do it? Even though we had done it so much.	There were times when students chose an option that I did not think was the best one, but it was best that I bit my tongue. Had to but my own self-interest aside, on lots of occasions. That is OK, everything these students do is great. If they were not making these compounds, they would not otherwise get made. [Organic] Every now and again you get a piece of data that prompts you to think in a different way. While we did not get data that was useful, we did get data that will encourage me to down certain tracks with a graduate student. The students also, found some interesting papers that I was not aware of previously. [Analytical]
Learning	I feel like I learned more from this lab than I would have from a traditional lab. I know previously in a traditional lab I do not take away as much as I think they think that we do because I'm more just trying to do the experiment and get the answer that they want.	Gratifying, so many little moments when a student runs down from the NMR lab to show me a beautiful spectrum shouting "we got it" was a thrill for me as much as them. To take something abstract from a textbook and making it concrete was really cool. So many times, I saw lights go off in peoples head, connecting a something from lecture. [Organic] I was pretty impressed by the presentations, exceptionally impressed by 3 or 4 of them. They were phenomenal. Of those, 3 I knew would be good, 1 was a surprise—blew me away. I never guessed that this kid could ask the questions he asked, answer the questions in a clear and concise way and that he had the background knowledge that he had. [Analytical]
Project Ownership	Yeah, I think all of you pretty much covered it. I honestly did not think I'd care about it as much as I did to begin with. But now, I'm invested, I guess. I want to know if the thing we made works	To me the greatest benefit, was going into lab and not knowing what was going to happen. It made every week really kind of exciting because I did not know where they were going to go. I did not know what the results were going to be. So, walking in there, I always had this incredible sense of enthusiasm because I just could not wait to see what they had accomplished over the last few days. And after teaching lab the old way for 20 years, that was huge. [Organic]
Confidence	I was like, OK, I think I actually know what I might be talking about right now. And just the names of things and the procedures and stuff like that. It definitely—even without instructions, you know how to run the rotovap or the HPLC. It got better as the semester went on.	And they grew a lot just from week to week. And I agree with you. When they got up and did that little 5 min elevator talk, I was like, wow. I could take these people to a conference and put them up in front of a room of people and probably convince them that they are real chemists. Yeah, they surprised me that day in a good way. [Organic]

Table 7. Alignment with Community of Practice Elements

Community of Practice Element	Theme	Codes
Domain: Area of shared concern	Working toward a Common Goal	Collaboration I Research Relevance
Community: Relationships built through discussion, and activities	Addressing Obstacles	Encountering Obstacles Iteration Collaboration II
Practice: Body of knowledge, methods, and tools	Understanding of Science Content	Discovery Learning Project Ownership Confidence

The theme **working toward a common goal** includes the codes *collaboration I*, *research*, and *relevance*, and paints the narrative of students working together to achieve a similar outcome. Student and faculty exemplars for this theme are

presented in Table 4. For example, a student directly emphasized the broader impact of the work, blood preservation, with each team focused on a piece of the project (Table 4, Collaboration I). In addition, many examples from the student

interviews included their understanding of research, how most research consists of not knowing the outcome, and how something unexpected can benefit future experiments (Table 1, Research). Finally, *relevance* is an important aspect of the CURE sequence because standard curriculum typically lacks this aspect,^{1,3} causing students to question “why am I doing this” or “why is this important”. In contrast, CUREs provide students with an authentic research experience that has relevance beyond the course; instances of students explaining the relevance of the research were prevalent in the student interviews (Table 4, Relevance).

The faculty experiences and observations were consistent with the student data for this theme. Specifically, faculty stressed the collaborations that occurred beyond the nested groups of three or four students. Both professors conveyed that creating an inclusive cross-collaborative environment was a goal for them as with their own research group (Table 4, Collaboration I). In addition, the analytical professor illustrated an added benefit of this CURE sequence, that the students were able to observe cross-disciplinary collaboration between the professors and the graduate teaching assistants who worked across both CUREs as well as in the faculty research laboratories. The faculty emphasized topics related to research, such as their need to play an active role in transitioning student expectations from their previous laboratory course experiences which were focused on the successful completion of an activity or synthesis of a known product. Early in the semester, reminders that “this is research” were necessary to keep students focused (Table 4, Research). However, the instructors saw that by the end of the course the students arrived at the ultimate benefits of the research experience. Finally, the faculty discussed ideas related to the Relevance of the CURE research. The research goal of investigating a possible blood preservative made the research relevant to students but was somewhat problematic in that it was a very long-term goal, not something to be achieved in a few semesters. The analytical professor described student frustration with the limited progress toward the goal (Table 4, Relevance).

A particularly defining moment for student understanding was at the end of the presentations when an audience member asked, “so, none of you made a blood preservative, what was the point?” After a brief pause the students erupted with explanations such as, “we learned things that will help” and “we learned what doesn’t work”.

The second theme, **addressing obstacles**, included codes *encountering obstacles*, *iteration*, and *collaboration II*. Student and faculty exemplars for this theme are presented in Table 5. *Encountering obstacles* depicted the narrative of students running into roadblocks while performing procedures or conducting instrumental analysis (Table 5, Encountering Obstacles). In addition, students discussed how certain obstacles effected subsequent experiments. Getting at the broader story of what was learned from an unexpected outcome and what was done to prevent this from happening again was reflected in the *iteration* code (Table 5, Iteration). Finally, the part of the narrative that brings this theme together is *collaboration II*, in which collaboration among groups was an important feature in tackling an obstacle that was encountered (Table 5, Collaboration II). For example, a student reflected about how they were able to ask for help from other groups if an outcome was not seen as a success. This ability to collaborate within a group and between groups helped bring multiple minds together to address obstacles encountered by individuals, groups, and the overall research project. Exposure to potential failure with research is

simultaneously a goal of the CURE and a potential obstacle.^{12,41} The faculty in this study kept the students motivated with positive reinforcement and reassurance that evaluation was based on participation in the process, not the results.

The third theme, **understanding of the scientific content**, revolved around the narrative of students engaging in science practices that allowed them to develop a deeper understanding of the science content in the CURE sequence. Student and faculty exemplars for this theme are presented in Table 6. The codes that were included in the development of this theme were *discovery*, *learning*, *project ownership*, and *confidence*. Each of these codes described details of a greater story being that students began to expand their knowledge by asking “why a certain instrument or technique was used” instead of the fear of being graded based on performance. For example, one student talked about how they had done an extraction before but had no idea why extraction was the correct method to use (Table 6, Discovery). It was not until participating in the CURE sequence that they began to develop a greater understanding than what was previously established. In addition, students reported being able to develop a more in-depth understanding of the scientific content being used (Table 6, Learning).

The CURE sequence introduced the content in a way that engaged students to develop a deeper understanding, putting meaning behind their actions. Students also indicated that by devoting time and effort into a research project they developed a “drive” to pursue further exploration into the science content presented in the CURE sequence (Table 6, Project Ownership). This understanding of the process of research is a key learning objective for the CURE model.

The final code involved in the development of this theme was *confidence*, as students discussed how they “lacked confidence within the field of science and chemistry specifically” and how that created a barrier, preventing them from feeling comfortable performing tasks without the help of the instructor. Participating in the CURE sequence helped them develop confidence and begin to identify as a scientist. This newfound confidence also enabled students to develop a better understanding of the content and finally feel they could use the equipment without instructions from the instructor (Table 6, Confidence).

The faculty experiences and observations were consistent with these codes. The discovery code was enthusiastically emphasized in the faculty conversations. The participating faculty felt their research benefitted in a variety of ways, from CURE students finding relevant papers to students producing unexpected chemical products, even in a single semester course (Table 6, Discovery). Even when unanticipated solubility issues limited the research utility in the analytical course, the professor saw benefits (Table 6, Discovery).

Student learning was an aspect of the CUREs that was perhaps most surprising to both professors. Their views were well aligned with prior research on faculty expectations of feeling self-fulfillment and satisfaction from teaching a CURE (Table 6, Learning).¹² Both CUREs ended with presentations by each team of students, and the instructors noted the ability of the students to explain the project generally and their work specifically (Table 6, Learning).

In answering the research question that guided this work, “What elements of a Course-based Undergraduate Research Experience allow development of a Community of Practice for undergraduate students?”, we have data to suggest that CUREs may indeed provide a Community of Practice experience for undergraduate students. To address our research question, we

evaluated whether the codes and themes reflected the Community of Practice.¹⁵ We concluded that the themes we documented corresponded well to the three primary features of the CoP learning model: *domain*, *community*, and *practice*. The emphasis of collaboration as a key design feature of the CURE model allowed for students to develop an understanding of research through interacting with other members of the CURE. This allowed students to engage in all three features of the CoP learning model. The alignment between the CoP framework and the three themes is summarized in Table 7.

The first characteristic of the community of practice *domain*, an area of shared interest that provides coherence to the community, aligns with the theme of **working toward a common goal**, where student *collaboration* in shared *research* provides *relevance* to the community. Although each group of students was focused on a piece of the larger project, the students connected with each other through their shared goal of “blood preservation”. The second element, *community*, is defined by the notion that relationships are built through discussion and activities. The theme **addressing obstacles** encompasses codes for *encountering obstacles*, *iteration*, and *collaboration II*. Science research is notorious for failed experiments, unexpected results, and a myriad of obstacles, which are managed by communities of researchers. The research community that evolved over the two-semester CUREs captures the depth and complexity of the CURE context. The third element, *practice*, describes development of a body of knowledge, methods, and tools which aligns with the third theme, **understanding science content**. The discovery, learning, and confidence codes align, in that learning refers to completely new techniques or skills while the discovery code was uncovering deeper understanding of a previous concept, technique, or skill; this expanded skill set and deeper understanding then boosted confidence. Finally, project ownership was grounded in the learning the process of research and appreciating the challenges.

LIMITATIONS

This CURE sequence was intentionally designed using the five elements of a CURE. Results of our study suggest that this intentional design can lead to students participating in elements of a CoP. This study was carried out with a CURE sequence that addressed related research questions. It is possible that other CURE sequences may not yield the same elements of CoP. The transferability of CoP elements to a variety of CUREs should be investigated to determine to what extent the five elements of a CURE result in students participating in a CoP. Despite this limitation, the results of the focus group discussions, the developed themes, and faculty substantiation are promising with regards to our research question.

IMPLICATIONS

The CoP theoretical framework that was adopted to guide the analysis of the qualitative data has allowed us to gain a better understanding of how CUREs function as a CoP as well as which aspects of the CURE correspond to the key features that make up a CoP.^{15,19} Of note is the duality of collaboration as key in achieving a common goal or shared concern of the community and in tackling obstacles that were encountered was a unique nuance to the CURE context because the students were working in nested groups focused on a version of the project addressed by the larger community. Williams and Reddish (2018) also noted two levels of collaboration working together as either focused on

a fragment of the research or as a larger community focused on full scope of the research.⁴⁰ This finding of collaboration at multiple levels is important for both education researchers and scholars of teaching and learning. Researchers should be aware of duality of collaboration as this could blur the meaning of collaboration depending on their research question. CURE designers should consider the degree that they might want to limit or facilitate broader collaboration. For those implementing or practicing pedagogical approaches that employ collaborative learning, e.g., project-based learning,⁴² guided-inquiry in lecture^{43,44} and laboratory,^{45,46} it is reasonable to consider the potential for these domains to develop in to a CoP. The key difference would be the role of the teacher or professor. CUREs are unique in that students and faculty conduct research side-by-side. Indeed, the CoP framework was developed to explore the apprenticeship model that existed in trade settings where a novice worked alongside an expert. Despite this difference, project-based and inquiry-based learning might well establish some elements of a CoP among students, particularly as they work together over extended periods of time.

Disciplined-based education research must have a theoretical framework that provides a lens for evaluating educational interventions. Lea contrasts different approaches that have developed from the use of CoP framework in higher education research and argues that efforts to employ the CoP framework should refocus their energies on using it to make sense of the learning that occurs in various contexts, supporting its heuristic application.²⁰ The CoP framework was adopted in this project for this very purpose, to understand the learning that occurred for students within a CURE. To be an apprentice is to engage in legitimate peripheral participation in a community of practice, which results in the situated learning of skills and knowledge needed to become an expert in the field.¹⁹

This study has provided insights from both student and faculty that support the notion of a CURE as a context for situated learning that can develop into a community of practice. The three themes that emerged from the student focus groups and the faculty interviews were shown to align with the CoP elements—*Domain* with **Working toward a Common Goal**, *Community* with **Addressing Obstacles**, and *Practice* with **Understanding Science Content**. This finding demonstrates the potential for elements outlined for CUREs in the literature (research practices, discovery, relevance, collaboration, iteration)^{3,35,47} to create a superior learning space, i.e., a Community of Practice, for both students and faculty. Providing this legitimate apprenticeship model within the standard chemistry curriculum provides access to this valuable experience for all students, thus increasing our capacity to realize potential solutions to the problems facing retention of students in STEM related majors, promote diverse career pathways for marginalized groups, and increase the enrollment in graduate education among minoritized students.^{4–6}

ASSOCIATED CONTENT

Supporting Information

The Supporting Information is available at <https://pubs.acs.org/doi/10.1021/acs.jchemed.2c00844>.

Interview Questions and Chi-Square Tables (PDF)
(DOCX)

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Notes

The authors declare no competing financial interest.

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