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A Composite Textual Phenomenological Approach to CUREs versus Traditional Laboratory Experiences

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Abstract

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Keywords

STEM undergraduate education, best practices, transmittal lecture, discipline-based education research, phenomenological theoretical framework

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Here we present unique perspectives from undergraduate students (n=3) in STEM who have taken both a traditional laboratory iteration and a Course-based Undergraduate Research Experience (CURE) iteration of the same introductory chemistry course. CUREs can be effective models for integrating research in courses and fostering student learning gains. Via phenomenological interviews, we asked students to describe the differences in their perspectives, feelings, and experiences between a traditional lab guided by a lab manual and a CURE. We found that (i.) critical thinking/problem solving, (ii.) group work/collaboration, (iii.) student-led research questions and activities, and (iv.) time management are the top four emergent themes associated with the CURE course. Students also indicated that they learned more disciplinary content in the CURE, and, importantly, that they prefer it over the traditional lab. These findings add another dimension of success to CUREs in STEM education, particularly surrounding student retention.

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Introduction

Course-based Undergraduate Research Experiences (CUREs) are increasingly heralded for their effectiveness in integrating research experiences in undergraduate STEM courses (Corwin Auchincloss et al., 2014; Corwin, Graham, & Dolan, 2015; Corwin et al., 2018). CUREs facilitate undergraduate research experiences for many students at once where historically research has only been available in an individual research laboratory setting ("apprenticeship style"; Harsh, Maltese, & Tai, 2011; Lopatto, 2003, 2010; Russell, Hancock, & McCullough, 2007; Taraban & Logue, 2012; Thiry et al., 2012; Zydney et al., 2002). A groupwork-based curriculum such as a CURE provides a more authentic research experience that effectively models collaboration with colleagues and peers (Bangera & Brownell, 2014; Corwin et al., 2018; Kinner & Lord, 2018) and may be more inclusive than apprenticeship style research experiences, and retains a diverse pipeline of STEM students (Staub et al., 2016). Jordan et al., 2014 highlighted a call to develop more CUREs as a way to foster students to "think like a scientist." Further, Brownell and Kloser (2015) provide a framework for measuring gains within student development in CUREs as compared with more traditional laboratory experiences. Moreover, more research is focused on the utilization and impact of CUREs on undergraduate learning gains (Brown, Cumming, & Pasley, 2017) and professional development across various disciplines (Kortz & Kraft, 2016; Lopatto, 2008, 2014; Wei & Wooden, 2011).

Similarly to discipline-based education researchers, more discipline-specific organizations have highlighted the importance of CUREs. For example, the American Association for the Advancement of Science (AAAS) included in their national call to action (2011) the need to develop CUREs to involve biology learners in conducting research (AAAS, 2011; Dolan, 2017). The literature describing CUREs to-date includes reports of increased student learning gains of science content and practices (Corwin et al., 2018; Bhatt & Challa, 2018; Caruso, Sandoz, & Kelsey, 2009; Harrison, Dunbar, Ratmansky, Boyd, & Lopatto, 2011; Kortz & Kraft, 2016). Recent studies document both the student learning gains, as well as their perceived understanding and interest in the CURE format—all through the lens of the undergraduate (Corwin Auchincloss et al., 2014; Gottesman & Hoskins, 2017; Hoskins et al., 2007) and of the graduate teaching assistants in the classroom (Heim & Holt, 2019). Furthermore, active learning strategies are acknowledged as best practices in undergraduate STEM education. Specifically, empirical research indicates that CUREs are more effective in fostering student learning than transmittal lecture models (Ambrose et al., 2010; Dolan, 2015; Eddy & Hogan, 2014; Freeman et al., 2014; Haak et al., 2011; Prince, 2004). These studies have assessed impact on students' prior knowledge, their organization of knowledge, motivation, mastery, practice with feedback, the way that a learner develops within a particular learning climate, and ultimately their ability to become self-directed learners (Ambrose et al 2010). Moreover, these paramount studies have contextualized their core findings by demographics, type of institution, and experience of the learner to better situate some of the findings described. Taken together, these findings expound upon the benefits of active learning strategies. Regardless, challenges with implementing inquiry-based learning or non-transmittal lectures remain, often citing lack of faculty time, support, and interest, and push-back from students (Michael, 2007; Miller & Metz, 2014). These reasons may simply be a byproduct of the lack of change in reward structure to faculty. For example, CUREs include more planning, the willingness to take risks, and such innovative approaches to pedagogy are often omitted from the promotion and tenure system.

While publications surrounding CUREs, and their pedagogical advantages for student learning are widely touted in the literature, as mentioned above and routinely highlighted in meta-analyses (Freeman et al., 2014; Theobald et al., 2020), these studies have utilized meta-data on overall retention as compared with case-matched data. Herein, we present a unique contribution of qualitative outcomes from students that participated in course-matched, instructor-matched, level-matched, prior experience-matched activities, and in succession (all within a one-year timeframe). These data serve as an additional window into the activities that influence student retention and the perceptions surrounding course styles that influence success where all other variables are controlled. Consequently, such data are very broadly applicable in scope, meeting the needs of an international audience based on the quality of data, rather than on the n-value such as in the a-forementioned meta-analyses. Finally, given that we could only examine such an experience retroactively, this adds uniqueness and impact to this approach.

Here we conducted semi-structured interviews with students that participated in a single course that included a traditional/cookbook lab (henceforth referred to as the "traditional lab"), and a CURE lab (henceforth referred to as the "CURE"). This composite textual phenomenological report is focused on "illuminating the specific, to identify phenomena through how they are perceived by the actors in a situation" (Lester, 1999, p. 1). We describe student-reported perspectives and experiences of a traditional introductory chemistry course lab experience, as well as a CURE version of the same lab course, after the same cohort of students participated in *both* courses. Importantly, this unique cohort of students were invited as participants in this study due to their unsuccessful completion of the course as a traditional lab section, and then their successful completion of it when offered as a CURE. It is rare to have the same cohort of students report on both a traditional lab course as well as a CURE course, thus we provide unique and valuable information to the discussion of CURE efficacy and implementation in undergraduate STEM education. The rationale of this study is to provide insight into the experiences of students who did not successfully complete the course the first time as a traditional lab but did so in the CURE format. This benefits undergraduate STEM educators, researchers, and those who are considering the value of a CURE curriculum within their department as we provide unique phenomenological comparisons of each instruction mode.

Research Question

Our study includes undergraduate students who have participated in both the traditional lab (having not earned a passing grade) and CURE iteration (having earned a passing grade) from the same introductory chemistry course. Thus, this study is well-aligned to answer the research question, "What are the differences in student perceptions of a CURE version and a traditional version of an introductory chemistry laboratory course?"

About the Researchers

Amie Sommers is a Ph.D. candidate at the University of Nebraska-Lincoln in discipline-based education research, with a background in ecology (M.S. from Texas Tech University). Her primary area of research is STEM educator professional development, but her research interests span undergraduate STEM education and workforce preparation. As Amie is experienced in both quantitative and qualitative research methods, she conducted the phenomenological interviews presented herein and led the qualitative data analysis via coding. Sommers' intentions in this project are to highlight the experiences of undergraduate students in both course formats to add to the literature and discussion of CURE implementation in undergraduate STEM courses.

Dana Richter-Egger, Ph.D. completed his graduate degree in chemistry in 2001 from the University of Missouri. At the University of Nebraska at Omaha, Richter-Egger is an Assistant Professor of Chemistry and Director of the Math-Science Learning Center. His research interests include environmental quality and STEM education. He regularly teaches both semesters of General Chemistry and has abundant experience teaching both associated laboratory courses. His interests include the further development of authentic scientific experiences for students in lecture and lab through incorporation of research and service-learning experiences into these courses.

Christine Cutucache, Ph.D. completed her Genetics, Cell Biology, and Anatomy degree in 2012 at the University of Nebraska Medical Center and has devoted the majority of her post-graduate career to understanding how students learn science. At the University of Nebraska at Omaha, she is the Haddix Community Chair of Science, Associate Professor of Biology, and Director of the STEM Teaching, Research, and Inquiry-based Learning (TRAIL) Center. She is experienced in mixed methods research, quantitative, and qualitative methodologies, including randomized control trials and well-matched comparison studies. Her interests for this project are to raise awareness for the less tangible learning outcomes that accompany experiential learning for students in an effort to embed more opportunities for students, and to ultimately retain more students within the STEM talent pipeline via the translation of best practices into the classroom.

Methods

Qualitative Theoretical Framework: A Phenomenological Approach

We chose a qualitative research approach to take full advantage of the unique circumstances of having the same students who completed the same course, within a single year (the first as a traditional lab and the latter as a CURE). Furthermore, we chose the phenomenological approach in order to gain perspectives in a meaningful way directly from the participants without the limitations of an exclusionary, already narrowed quantitative survey instrument. To capture these voices, we focused our research questions around the phenomenological experiences of the students within each of the courses to provide context to these experiences in a way other research methods cannot address as richly as qualitative methods are able. Our study is rooted in the phenomenological theoretical framework (Husserl, 1913/1983) as we followed a composite textual phenomenological approach. Phenomenological-based studies seek to elicit the meaning and essence of a lived experience, both to individuals and groups of people (Simon & Goes, 2011). Here, we ask students to describe the differences they perceive in a traditional lab and a CURE. The methods that we employed in our study include semi-structured interviews that use guiding questions to elicit students' experiences and feelings to understand their perceptions of learning in a CURE and traditional laboratory course (Lester, 1999; McNamara, 2009; Moustakas, 1994;).

Participant Recruitment

As approved within our IRB # 511-15-EX, we asked students who participated in both the traditional version of the Chemistry (CHEM 1194) course and the CURE version of the course to participate in individual, semi-structured phenomenological interviews that lasted between 20 and 40 minutes in the Fall of 2018 (n=3; Creswell, 2016; McNamara, 2009). Students were selected based on their unique perspectives given they participated in both the traditional lab and CURE iterations, and their voluntary consent to participate in the interviews, with all responses de-identified.

Data Collection

Prior to the start of the interview, we asked participants for their informed consent to participate and permission for the interview to be recorded. We also informed participants that all personal information would be kept confidential (including the removal of identifiers from transcripts and data collection) and instructed participants to not use names or other identifiers in the interviews. To ensure participants were able to provide an informed perspective on both course versions, we conducted interviews the week following the completion of the CURE (students had participated in the traditional lab prior to the CURE).

According to the semi-structured phenomenological interview framework, we began the interviews by asking students open-ended, guiding questions, including descriptions and perspectives of their general experience in both courses, academic performance, feelings of efficacy in content and research skills and techniques, and overall preference between the traditional lab and the CURE (we included specific questions asked of the participants in Table 1; Creswell, 2016; Lester, 1999; McNamara, 2009; Moustakas 1994). The open-ended questions allowed the interviewer to follow up on students' answers, thus gaining further insight and detail into their meaning and intention and to aid in context. Finally, as per best practices surrounding phenomenological interviewing (i.e., Creswell, 2007; McNamara, 2009; Smith, Flowers, & Larkin 2010), the interviewer established rapport with the interviewees to make them comfortable with conversation, and provided: 1) a place with little distraction, (2) the purpose of the interview to the interviewee, (3) addressed confidentiality, (4) an explanation of the interview format, (5) a typical response length context, (6) contact information for how to contact interviewer if desired, (7) the opportunity for participants to ask questions before beginning the interview, and (8) a way to record the interviews, instead of relying on memory to recall responses. These practices align with Moustakas (1994), allowing collection of "rich, vital, substantive descriptions of a phenomenon" (p. 116) and allowed for flexibility with the open-ended responses. We conducted all three interviews in person and subsequently transcribed them to accurately capture responses.

Table 1
Questions asked to participants to glean phenomenological information surrounding the CURE intervention.

Phenomenological Interview Questions
1. Describe your experience in both the traditional lab and the CURE, including any positive and negative experiences.
2. Which course do you feel you learned more in, and were there any activities or experiences in particular that you felt were important to your learning?
3. What type of skills did you learn/gain in the traditional lab, and the CURE?
4. Which course did you like more, or have more fun in, and why?
5. Which course do you feel prepared you (or was more applicable) for your career goals, and why?
6. Which course was more time consuming (both in class and outside of class), and what activities took up your time in each?
7. What are the overall differences you observe between the traditional lab and the CURE?
8. Which course would you recommend to your peers, and why?
9. If you had to take another chemistry course as a traditional lab or a CURE, which would you pick, and why?
10. Overall, which course did you most prefer, and why?

Data Analysis

To identify emergent themes within the data, we analyzed the transcribed interviews of the three participants. Sanders identified n=3 as having sufficient qualitative information to inform a study (Sanders, 1982) so we followed that guidance in our study. Based on initial read-throughs of the interviews, we identified preliminary emergent themes. Next, we reached out to the students who participated and conducted respondent validation, ensuring our understanding of the text was aligned with their intended meaning. Finally, we added composite, textual, and structural responses to include situation, context, and understanding with responses.

After we identified the preliminary emergent themes, we examined the coverage of these coded themes using NVivo 12 (©QSR International, Victoria, Australia) for Mac. These data included frequency, coverage of the text, and alignment between participants. Following, we coded each interview for (1) emergent themes, and (2) by course version (traditional and CURE) such that we could compare the courses and their associated themes. Next, we refined our list of emergent themes for redundancy and overlap based on the student interview responses and finalized the emergent themes (Nelson & Cutucache, 2017). Taken together, we provide textual reference after coding these responses to align with phenomenological outcomes.

Data Rigor and Trustworthiness

To ensure rigor and trustworthiness of our data, we first ensured the interviewer was not directly involved in the CURE intervention/course, allowing students to speak openly regarding their experiences and preventing student and interviewer bias (Creswell, 2016; McNamara, 2009). Following, we used respondent validation to establish credibility and reliability and ensure that students' perspectives were accurately captured (Moustakas, 1994). Finally, we integrated multi-researcher read-throughs and interpretations, and interviews were coded by two project team members to minimize bias (Moustakas, 1994).

Results Organization

Within our results section, we first describe the Traditional lab and CURE sections, to provide context for the results from our interviews. Then, we report the top four emergent themes from interviews based on percent coverage of text (n=3) of students' perspectives on both a traditional lab and CURE version of the same introductory Chemistry Course (CHEM 1194). These top four emergent themes are derived from the coding we conducted in NVivo 12©. We support our emergent themes with relevant quotes from the interviews that best support our findings.

Results

Rationale for a Phenomenological Approach

We utilized a phenomenological, qualitative approach for this study in order to gain perspectives and perceptions from participants in a meaningful, unassuming way. This approach allowed us to collect information as a third party, to ultimately aid in the candid nature of responses. Moreover, the utilization of qualitative methods for this study were imperative to capture as broad and deep of data as are available, without the use of an already exclusionary instrument such as a survey that does not allow for free-response and subsequent follow up for context and genuine understanding. Furthermore, with this being the first study of this kind (participant matched, rather than simply a "pre/post" intervention study), it was imperative to ensure that we gained information that could subsequently be used to develop a pilot rubric and subsequently an assessment and/or survey instrument.

Chemistry Traditional Laboratory Context

The traditional chemistry laboratory meets for ~3.5 hours once a week for 15 weeks per semester. Each week is a different, isolated experiment guided by laboratory manuals with known experimental outcomes, most of which coincide with concurrent topics in the lecture. Students learn and reinforce topics in common (equilibrium, kinetics, thermodynamics, etc.) and associated lab techniques (especially those used for qualitative and quantitative chemical analysis) guided by a laboratory manual and instructor.

Chemistry CURE Context

We classify the CHEM 1194 CURE as such using the 5 characteristics outlined by (Corwin Auchincloss et al., 2014) that distinguish CUREs from other laboratory learning experiences: (1) use of scientific practices, (2) collaboration, (3) discovery, (4) iteration, and (5) broadly applicable experiences. The central intent of this CURE is for the students to learn science (chemistry) by *doing* science. By "doing" science we mean research. In lecture, students learn *about* chemistry. In a traditional laboratory, students are "doing" in the sense that they are active, but their activities are still centered on learning *about* chemistry. The CURE section is different in that the students are *doing scientific research.* The content knowledge focus remains the same as the traditional lab, including chemical topics, skills, and knowledge, but we do so with additional emphasis on (1) the application of the chemistry, (2) the process of scientific research, (3) scientific communication, and (4) the collaborative and interdisciplinary natures of science. Ideally, students still gain the skills and knowledge typical for the course in addition to developing their research skills. In this way students are better prepared to move into future research opportunities in their undergraduate degree or in a STEM profession.

This CURE section met on the same schedule as the traditional laboratory section but was built around a semester-long research theme of environmental analysis. The students were divided into groups of three. Each week, time was devoted to a student-led research project and the related skills focused on developing a scientific question, collecting soil, water, and plant samples, analysis of the samples, and interpretation of the results. The research skills practiced were: forming research questions, reviewing the literature, proper sample collection, instrumental techniques used for sample analysis, interpretation of results, scientific communication, and collaboration. Five of the experiments from the traditional lab were retained, modified, and integrated into the research. The last two weeks of the semester were reserved for scientific communication (after rough drafts and revisions) in the form of oral and poster presentations at a campus research symposium.

Emergent Themes

Following our qualitative coding of responses, we observed four emergent themes. These themes included *Critical Thinking and Problem Solving, Group Work/Collaboration, Student-Led Activities and Research Questions, and Time Management.* The corresponding coverage and example student quotations supporting each theme are included below.

Critical Thinking and Problem Solving:

The most prevalent emergent theme (i.e., critical thinking and problem solving), represented 31.02% coverage of student. Students discussed in-depth the challenges they faced throughout their group research projects and subsequently their response to these challenges, including shifting their research question focus and adapting to unforeseen methodological issues. For example:

> *If we went with a question, it was more what you think is going to (sic) work, so it was more us figuring out as a group what would work best for our research opposed to someone telling us well this is how you fix it.*

While this student does not directly state an improvement of critical thinking skills as a result of participating in the CURE, it is evident here and throughout the interview that this student was required to think critically both individually and as a group in order to move forward with the research project.

Group Work/Collaboration:

This emergent theme represents 22.21% coverage of all combined interviews. Students mostly discussed working collaboratively within the context of their small groups. However, it was also mentioned that there was inter-group communication and collaboration, particularly in reference to critical thinking and problem solving in troubleshooting unforeseen hiccups and complications. For example, *"We would all get together as a class and kind of talk about where we are going and everything like how are things going, but then we would break up into our smaller groups."* Students also spoke positively about group work and collaboration, as they expressed feeling more confident in their work with the support and guidance of their peers. For example, *"I liked working in groups, it kind of helped my anxiety to have somebody else say, 'yeah this is right'."*

Student-Led Activities and Research Questions:

This theme represented 21.26% coverage of all combined interviews. Students spoke positively about their experiences in creating research questions and activities, and indicated they preferred this to laboratory manual-guided experiments in the traditional lab. For example:

> *In the CURE group it was very clear that it was more of a choose your own adventure type of class where we didn't have a set of workbooks that we were working out of. We didn't really even know what we were going to be doing in the next week.*

Throughout the interviews, students spoke of this "choose your own adventure" setup with positivity and excitement, contrasted with their tired descriptions of the cookbook labs. However, students did indicate a sense of uncertainty in light of the "freedom" of the CURE and described some unknown in the day-to-day expectations without typical guidance from a lab manual or instructor, as illustrated here: *"Because I didn't know what was expected of us, I spent like a lot of class time just standing around wondering what I am supposed to be doing."*

Time Management:

This theme represented 20.33% coverage of all combined interviews. Heavily correlated with the previous emergent theme, Student-Led Activities and Research Questions, students described trial and error experiences in time management both in daily tasks as well as overarching timelines to complete their research projects. For example:

> *Trying to figure out when the right time to start something would be like "When should we have planted our plants and when should we contaminate them?", and just things we hadn't thought of until it was too late to think of them.*

Students described time management skills as a steep learning curve, expressing frustration over lost time or wasted effort. However, they iterated the benefits of these as learning experiences for future research and project management.

Textual and Structural Context of Emergent Themes:

Beyond these top four emergent themes, we feel it is important to report that there are several other themes that students associated with CUREs and not with the traditional laboratory experience, including Community Involvement and Volunteering, Research Interest, STEM Professional Development, Communication, Ownership, and Networking (Figure 1). These themes were nearly ubiquitously discussed as positive experiences, with students indicating they valued these experiences and benefited from their inclusion in the CURE. For example:

> *I was more invested in the research symposium that was last week that we weren't required to go to because class wasn't in session, but that was kind of one of the things that I was like well I worked on this (and) I worked on the poster, I'm going to go.*

Attendance at this symposium had originally been a requirement of the course, but the university was closed in honor of the late President Bush's funeral. As such, students were not obligated to attend. This quote reveals the students' deep commitment to communicating their research findings and ownership of their hard work throughout the semester. Another example demonstrating the interviewee's networking and professional development gains during the course is quoted here: *"I got to see the research that was being done around me and I got to get involved in that, and I think that was really useful."* This student was describing the benefits and inspiration of being part of a larger group all working and supporting each other in multiple interrelated research projects. Doing the research was good, but doing it in the presence of others who were doing related research was even more useful. To that end, students also positively discussed communication and discussion with their peers. *"In the CURE lab we would have a lot of discussion."* Having taken both the traditional lab and the CURE, these students were able to pick up on aspects of the CURE course that their classmates may not have been as aware of as they lacked the perspective the comparison afforded. In this case, these students noticed more discussion and thought among their peers, whereas in the traditional lab students were quiet, only following instructions listed in the lab manual. The students we interviewed also noted the broader applicability of skills they learned in the CURE compared to the traditional lab, as described here: *"The CURE has more of the skills I learned that are applicable to a much wider base of problems."* These students recognized the broad value of the CURE, and that they gained much more than technical experience. They recognized the value of having engaged in the process of science, compared to following procedural instructions as is most common in the traditional lab.

Interestingly, the only theme associated with the traditional lab that was not discussed in reference to the CURE was "Instructor and Laboratory Manual-Guided Learning" (Figure 1). While describing their experiences with student-led research questions and activities in the CURE, students contrasted this experience with the instructor, teaching assistant, or lab manual-led experiments associated with the traditional lab, often indicating these as negative or frustrating experiences. For example:

> *Because of the way the workbooks were structured, the way the instructors don't really know the material I struggled a lot in those contents so though I might have gotten more of the content knowledge it was begrudgingly and with a lot of struggle.*

There are several themes that were shared between the traditional and CURE labs, including Content Knowledge, Research Skills and Techniques, Morale, and Academic Performance (Figure 1). Students struggled with the unknown nature of a scientific research project, even suggesting that the instructors don't know the material—even though no participant will know the outcome until the experiment is complete, as is by design with a CURE. While students discussed these themes in relation to both course variations, it is important to note the context in which they were discussed. For example, students often described the Morale of the CURE course as high, indicating the course was fun: *"…but with the CURE class, everyone was pumped to be there."* However, in reference to the traditional lab, students described their frustration with the activities and learning process, noted here: *"I feel like a lot of students left that class frustrated every day and then that can be really disheartening especially as a group because you hear each other complain about it."*

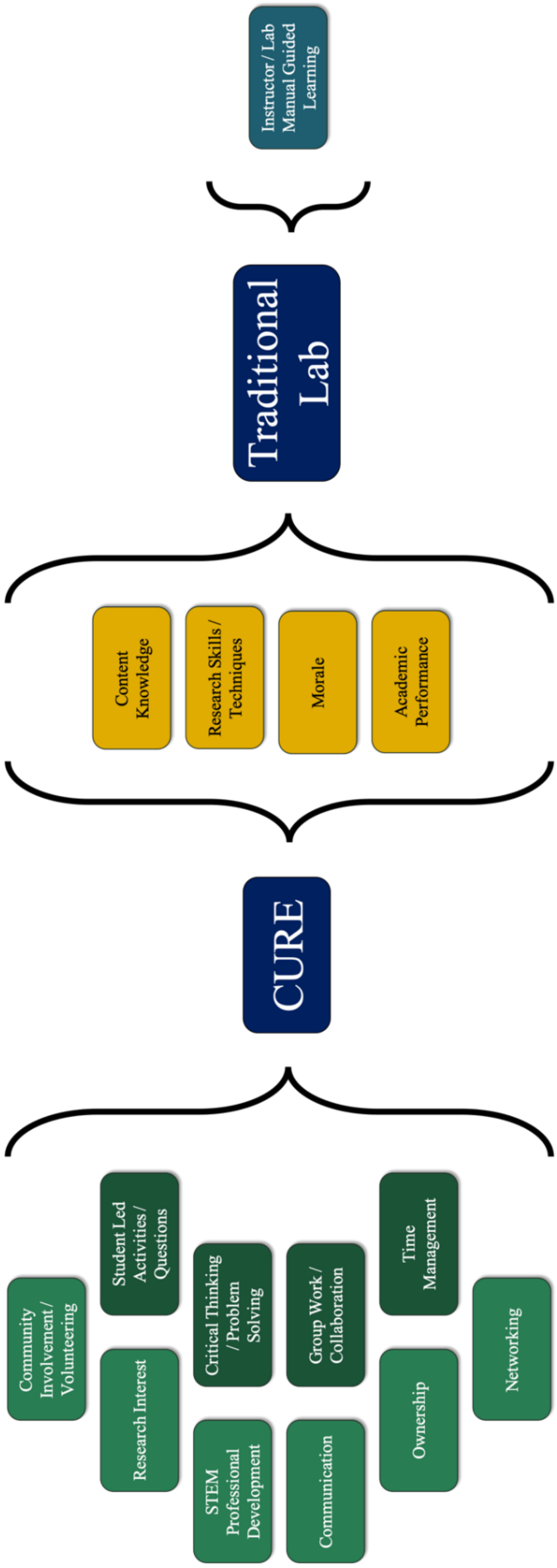
Students discussed Research Skills and Content Knowledge in similar ways. Several times students indicated that the traditional lab was beneficial with more research skills, techniques, and content knowledge, but that it felt rushed and they were unable to comprehend all the information given: *"…little bit too fast paced to the point where I kept doing work and hoping it was good but I had to finish everything so quickly I couldn't fundamentally understand what I was even doing."* However, the students were not asked if they learned to develop resiliency and perseverance as a result.

One student indicated that while the traditional lab covered more content and research technique material, they were able to gain a "deeper" understanding of fewer content areas and research skills as a result of a more manageable learning pace: *"For the CURE you focus in depth on fewer things and I got to really go and like understand what I was working on."* Interestingly, students felt they learned more through the CURE, both in content knowledge gains and other professional development skills. For example: *"I actually learned more in the CURE lab."*

To gain overall insight to which course students preferred, we asked which they would take again, and which they would recommend to others in STEM. One student indicated that if they were recommending a course to someone only interested in content knowledge, they would suggest the traditional laboratory. However, all students indicated that overall, they preferred the CURE over the traditional lab as it provided more than just content knowledge and was generally a more interesting course to take. For example, *"I still prefer the CURE lab, it was more self-guided."* Such a response demonstrates the appreciation for independence and leadership, and the ability for students to seek questions to their own answers—these are all fostered via a CURE environment and may lead to increased retention of struggling students in STEM disciplines.

Figure 1

All themes coded to the CURE and traditional laboratory version of CHEM 1194. Themes that are combined (e.g., Group Work/Collaboration, Instructor/laboratory manual guided learning) are done so because students discussed them as one concurrent theme or experience.



Discussion

Our study provides a unique contribution to research regarding undergraduate student perceptions of STEM learning, as this cohort has taken *both* the CURE and traditional laboratory version of the introductory Chemistry course (CHEM 1194). The timeliness of our results echo the sentiments of existing highlights including a news article and meta-analysis (*What is a Textural and Structural Description?* according to Moustakas, 2011; Theobald et al., 2020, respectively). Consequently, we aim for these qualitative descriptions to aid in directing future course structure for student benefit.

Students overwhelmingly discussed positive learning experiences associated with the CURE course (as evident by the emerging themes; Figure 1). In particular, students discuss critical thinking/problem solving as a regularly occurring theme throughout their group research projects and experience in the CURE. STEM employers call out critical thinking and problem solving as highly sought-after skills in professionals entering the STEM workforce, with over 90% emphasizing their importance and value even over content knowledge (Carnevale & Smith, 2013). Thus, it is imperative to foster these skills in undergraduate STEM education, and their presence in this CURE (as perceived by students) is promising. Similarly, students describe learning experiences in the CURE that foster group work and collaboration, student led activities and questions, and time management, among others. These skills are all necessary in successful employment, yet they are underdeveloped by many STEM programs. CUREs can be effective in fostering learning gains (e.g., Bhatt & Challa, 2018; Caruso, Sandoz, & Kelsey, 2009; Corwin et al., 2018; Harrison, Dunbar, Ratmansky, Boyd, & Lopatto, 2011; Kortz & Kraft 2016), and our data indicate that they help to foster professional development skills as well (e.g., critical thinking/problem solving, group work/collaboration, and time management themes; Figure 1) adding another dimension of success to CUREs. Our study further highlights the importance of incorporating research experiences that are available to a greater number of undergraduate students (such as CUREs) within STEM programs.

Students did not associate the traditional laboratory with the same positive learning experiences as the CURE (Figure 1). The only theme that was associated with the traditional lab and not also shared by the CURE was Instructor/lab manual guided learning (Figure 1). Students discussed instructor and lab manual guided learning together, both in contrast to the perceived freedom and autonomy of the student led activities and questions associated with the CURE. While students indicate that the freedom to choose their own research question, project, and workflow was challenging, they state that the limitations of lab manual-guided learning leading to a known answer were frustrating and demoralizing, and they preferred the CURE style of learning where they were researching their own questions without a known outcome.

Summary

There were several themes that students discussed in relation to both the CURE and the traditional laboratory, and it is important to note the compare and contrast fashion in which these themes were articulated (Figure 1). The theme Morale was referenced as a positive when discussing the CURE, where students indicated they had fun with their groups and designing their own research projects, but that the traditional laboratory was frustrating, especially in regard to working individually within the limitations of cookie-cutter lab manual experiments. Where the goal is to foster a successful learning environment, our study indicates that morale may impact students' perceived gains and success. Students indicated that the traditional laboratory may have included *more* experiences that fostered content knowledge and research skills and techniques compared to the CURE. However, they also indicated that the pace in which material was covered made learning difficult, and that they preferred the "deep" content knowledge they gained on their research topics in the CURE. While it is necessary to cover certain topics in a general undergraduate education (particularly in Chemistry), the "deep" content knowledge learning style is more akin to "real-life" research, and students recognized the benefit of gaining experience that is applicable in STEM careers. As a result of this deeper content knowledge and experience with research skills and techniques, in addition to the perceived gains in critical thinking and problem solving, students indicated that they felt they had actually learned *more* from the CURE, including more translational information applicable across disciplines (Figure 1). These data support progression in learning toward mastery, including scaffolding (Chickering, 1969; Roediger & Karpicke, 2006). Moreover, increase in student confidence is reported to correlate with positive outcomes at younger levels of education (Gunderson, 2013), and might also play a similar role at the undergraduate level.

It is imperative to highlight that students favored the CURE course overall, as indicated by their preference on which course they would take again, which they would recommend to another student in STEM, and which they generally preferred. As researchers, we found this strong positivity towards the CURE over the traditional lab a surprise. The appeal of the CURE experience seemed universal among the students, regardless of major, level (freshman, sophomore, junior, senior), traditional vs. non-traditional, chemical aptitude, previous research experience, etc. We were not expecting to discover the extent to which students recognized and articulated the benefits and distinctiveness of the CURE lab over the traditional lab. While student preference may not be as persuasive of a finding as the presence of critical thinking or research skills and techniques, a lack of student support remains one of the barriers to employing other active learning strategies throughout STEM undergraduate education (Michael, 2007; Miller & Metz, 2014). Thus, the overwhelming student preference and support for CUREs that we observe here should be a catalyst in conversations of undergraduate STEM pedagogy overhaul.

Future Directions

The next steps in furthering CURE efficacy research would be to combine our phenomenological data on student perceptions of learning gains with quantitative analysis of these emergent themes, particularly critical thinking and problem solving as they were the most prevalent and are so valued by STEM employers (Carnevale & Smith, 2013). Additionally, future research questions should focus on student resiliency and grit (perseverance and passion for long-term goals), in light of challenges and adversity in STEM courses (Duckworth et al., 2007; Egenrieder, 2010; Howe, Smajdor, & Stöckl, 2012). Students described encountering challenges in both the CURE and the traditional lab (e.g., overwhelming amount of content knowledge in the traditional lab, lack of specific direction in the CURE), and future research efforts should elucidate the roles of resiliency and grit (or their perception thereof) in students' success in courses necessary to achieve their career goals, and whether these courses can foster perseverance in students. Such research efforts can address undergraduate retention in STEM, particularly in disciplines and courses with low retention (e.g., Chemistry).

Our study indicates that, contrary to previously reported student pushback on active learning, undergraduate students overwhelmingly preferred the CURE version of the Chemistry CHEM 1194 course to the traditional lab version. This, in addition to the student-perceived learning gains in critical thinking and problem solving, time management, and collaboration skills, serves as more evidence in favor of broader implementation of CUREs throughout undergraduate STEM education. The generalizability of our findings to other CUREs and STEM undergraduate student populations is high. First, our findings are from a population of students who took *both* the traditional lab and CURE lab—thus providing unique insight and ability to compare and contrast each course. Additionally, our results are consistent with the literature describing the benefits of CUREs, especially to underrepresented minorities in STEM (Bangera & Brownell, 2014; Corwin et al., 2018). Finally, the students who participated in this study (and both the CURE and traditional lab courses overall) represent diverse majors, chemical aptitudes, and research experiences, allowing for broader comparisons throughout undergraduate STEM education.

Limitations

This study is limited in a number of ways. First, we had a small number of participants (n=3). This is primarily due to the limited number of students who took the traditional lab, did not pass, and repeated the course as a CURE. Additionally, we are limited in that we are comparing only a single semester of each course. It is possible that these students may have provided different information if the research focus of the CURE had been different, as this can change from semester to semester. These limitations can be addressed by repeated investigation into these research questions, but we would again be limited in the number of students who had taken both the traditional lab and the CURE. We attempt to mitigate these limitations by highlighting their phenomenological experiences as opposed to quantitative research outcomes, the quality of their laboratory work, or grades earned in each course. Our study design eliminates one of the largest uncontrolled variables in most other accounts of CUREs in that those students normally compare their CURE experience to prerequisite and/or unrelated courses whereas students in our study are comparing two versions of the *same* course.

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