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Experiences of Undergraduates and Graduate Teaching Assistants in Biology Course-Based Undergraduate Research Experiences

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by

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Abstract

Evidence of positive student outcomes from course-based undergraduate research experiences (CUREs) has sparked implementation of CUREs in introductory biology laboratory courses, as one approach to boosting student engagement in research. In a CURE, students collaborate with other students and instructors on a research project, where they conduct novel scientific research that has relevance to a local or scientific community. However, previous research rarely considers that graduate teaching assistants (GTAs) often teach introductory labs. The classroom role of GTAs expands in a CURE—they no longer need to simply teach a lab class, but also to serve as research mentors. GTAs, who may be novice researchers and/or teachers, likely vary in their interest and capacity for teaching a CURE, which could impact their students' experiences. In this work, we explore undergraduate student experiences in a CURE, the barriers that GTAs face in learning to adopt evidence-based teaching practices, and the challenges and impacts of utilizing GTAs as CURE instructors.

We first aimed to identify the elements of a CURE that influence students' perceptions that they are engaging in an authentic research experience. Through analyzing written reflections collected throughout a CURE, we learned that experiencing failure, in conjunction with perceiving the CURE design element of broadly relevant novel discovery, can be a powerful and productive experience that contributes to student perceptions of engaging in real scientific research. CURE instructors should therefore carefully facilitate student perceptions and experiences with failure and relevant discovery.

We then explored how graduate students adopt evidence-based teaching practices in general. Through interviews, we learned that many biology graduate students place high value on evidence-based teaching. However, some struggle to adopt evidence-based practices into their teaching, due to barriers such as training, limited autonomy in the classroom, and perceptions that teaching is not valued within their graduate studies.

To explore the impacts of GTA-taught CUREs, we designed a case study at a research-intensive institution, where GTAs teach CURE lab sections in the introductory biology curriculum. We used Expectancy-Value Theory, Self-Determination Theory, and the framework of essential design elements of a CURE to guide our approach to both data collection and analysis. During a single term, we: 1) interviewed GTAs and a selection of their students; 2) conducted in-class student focus groups; 3) administered multiple surveys, including both open-ended questions and the Laboratory Course Assessment Survey to measure perceptions of participating in essential CURE elements; and 4) asked students to complete a worksheet regarding their perceptions of the lab objectives that their GTAs emphasized. Teams of researchers developed codebooks to systematically analyze interview, focus group, and open-ended survey data.

We found high variability among GTAs, both in their value and perceptions of their role as a CURE instructor, and in the experiences of their students. From interview data with GTAs, we established three profiles to describe GTA perceptions of their role as CURE instructors: "Student Supporters," "Research Mentors," and "Content Deliverers." Most of the GTAs perceived that their role in the class should be to both support their student's affective needs in the classroom ("Student Supporter") and to develop their student's autonomy and competency as researchers ("Research Mentors"). However, some GTAs did not describe balancing these roles.

In class-wide focus groups, students of different GTAs described differences in their classroom environment: while some GTA's students reported that their GTA was highly capable in creating a positive and supportive learning environment, others reported that their GTA created a negative and unsupportive lab environment. Students who described supportive environments also reported experiencing more of the essential CURE elements, such as collaboration, iteration, and recognizing the relevant discovery aspects of their work. Students reported GTA-driven differences in the objectives that were emphasized in their labs, and GTAs also impacted student perceptions of whether their institution implemented CUREs for student-centered or non-student-centered purposes.

We further explored the mechanics of how a GTA's support impacts students' experience in the classroom through interviews with students. Students who perceived that their GTA was unsupportive of students' competency, autonomy, and relatedness (or sense of belonging) in the classroom were less likely to experience high autonomous motivation in the CURE. Autonomous motivation also appeared to be positively related to perceptions of experiencing essential CURE elements.

Our case study revealed differences in GTA's conceptions of their role in the classroom and patterns in the experiences of their students, such that students of some GTAs experienced high support and a positive classroom environment, which fostered student motivation and perceptions of engagement with essential elements of the CURE. However, students of other GTAs did not receive this support. Therefore, we may not be offering students equitable opportunities to engage with research through GTA-taught CUREs, depending on the capacity of individual GTAs to support their students and facilitate essential design elements in the CURE.

I dedicate this to the many phenomenal women in my life—Grandma Wilma, Mom, Jayne, family, friends, and mentors—all who have inspired me and taught me to be strong, independent, hardworking, and to pursue doing the things I love.

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List of Abbreviations

BER: Biology Education Research

CUREs: Course-Based Undergraduate Research Experiences

A style of laboratory course designed to engage students in authentic research projects while experiencing five essential elements: Scientific Practices, Collaboration, Iteration, Broader Relevance, and Novel Discovery

DOI: Diffusion of Innovations

Theoretical framework describing the process a motivated individual takes in deciding to adopt an innovation

EBT: Evidence-Based Teaching

Student-centered teaching strategies, with research supporting the effectiveness of the strategy

EVT: Expectancy-Value Theory

A motivational theory suggesting that one's value for a task (Attainment, Intrinsic, Utility, and Cost) and expectancy to succeed at that task will impact their achievement-related choices

(G)TAs: (Graduate) Teaching Assistants

LCAS: Laboratory Course Assessment Survey

Survey instrument designed to measure student perceptions of experiencing elements of Collaboration, Iteration, and Relevant Discovery in a CURE

LSGSS: Life Sciences Graduate Student Survey

An online survey designed to explore life science graduate students' experiences with various evidence-based teaching strategies

SDT: Self-Determination Theory

A motivational theory suggesting that basic needs of Autonomy, Competence, and Relatedness must be met in order to support student's autonomous and self-determined motivation

STEM: Science, Technology, Engineering, and Math

Chapter 1

Introduction

Narrative Overview of Work

As an undergraduate, I had the opportunity to conduct research in a faculty member's lab, and it was the single most impactful and transformative experience of my undergraduate education. When I doubted my ability to succeed in science because of the poor grades I earned in introductory biology and chemistry courses, my scientific self-efficacy was bolstered by the competency I knew I was developing in my research skills and the positive recognition I received from my research mentors. When I felt isolated among my hyper-competitive classmates and was too afraid to approach my professors during office hours, I felt a sense of belonging within my research lab, and received social, academic, and professional support from my peers and research mentors.

All of these benefits, and more, are experienced by many Science, Technology, Engineering, and Math (STEM) students who have the opportunity to participate in undergraduate research experiences. There is a wealth of evidence suggesting that participation in apprentice-based research experiences provides benefits including increased student motivation, scientific self-efficacy, scientific research skills, interest in science, sense of belonging in STEM, and, ultimately, retention in STEM fields (Eagan et al., 2013; Estrada et al., 2018; Laursen et al., 2010; Lopatto, 2007; Robnett et al., 2015; Seymour et al., 2004).

Unfortunately, opportunities to participate in such beneficial research experiences are not available for all undergraduate students, as space and resources in faculty-led labs are limited. Further, access to these opportunities is inequitable, and influenced by demographic and socioeconomic patterns both in the students who seek out research opportunities and in the students that faculty accept into their research labs (Bangera & Brownell, 2014). In the past decade, there has been a resulting push to increase equitable access to research opportunities for undergraduate STEM students (Brewer & Smith, 2011; National Academies of Sciences, Engineering, & Medicine, 2015; National Academies of Sciences, Engineering, and Medicine, 2017; Olson & Riordan, 2012).

With the goal of increasing these research opportunities and addressing equitable access to research, one strategy that institutions are employing is integrating course-based undergraduate research experiences (CUREs) into standard undergraduate curriculum (National Academies of Sciences, Engineering, & Medicine, 2015). There is particular interest in employing CUREs in introductory courses, where they may be especially beneficial to students, as introductory courses reach the greatest number of students (National Academies of Sciences, Engineering, & Medicine, 2015). In a CURE, students collaborate on research projects, often within the context of a standard-enrollment laboratory class (Auchincloss et al., 2014). While students in inquiry-based laboratory courses also often engage in science via practicing experimental design, using scientific tools and gathering and analyzing data, CUREs are distinct from inquiry courses because of the opportunity for *broadly relevant novel discovery*—the research questions that CURE students address should be unknown to the greater scientific community, and should have a relevance that extends beyond the classroom (Auchincloss et al., 2014; Brownell & Kloser, 2015). There are two commonly-used models of CUREs: 1) independent CUREs, which are developed by individual faculty members and engage students in projects that often align with the faculty member's own research program; and 2) network CUREs, where a format for student projects is designed and packaged into a curriculum that can be implemented at multiple institutions, allowing faculty instructors to bypass some of the challenges that come with developing an independent CURE curriculum (Shortlidge et al., 2017). There is evidence that participation in CURE curricula offers students many of the same benefits as seen from participation in apprentice-based research experiences, such as increased scientific skills, scientific self-efficacy, interest and understanding in the process of science, and increased motivation and retention in STEM (Harrison et al., 2011; Indorf et al., 2019; Jordan et al., 2014; Reeves et al., 2018; Rodenbusch et al., 2016).

As an undergraduate, I had the opportunity to participate in a network CURE during my senior year, and experienced many of these benefits first-hand. The CURE I participated in used the HHMI SEA-PHAGES curriculum (Jordan et al., 2014), where students isolate bacteriophages from student-collected soil samples, design experiments to characterize properties of their phage, and annotate their phage's genome. Due to the enormous diversity of bacteriophages, students nearly always isolate a novel phage, and physical characteristics and genomic information about their phage is uploaded to an online database, where scientists could potentially use the information in the future (Jordan et al., 2014). Despite already having three years of research experience, the CURE was an eye-opening opportunity for me: for the first time, I felt like I was experiencing the process of science from start to finish. Additionally, I experienced some aspects of the scientific process that had been missed in my apprentice-based research experiences—particularly in thinking about experimental design and in contextualizing and communicating my findings.

However, the CURE was markedly different from my apprentice-based research experience, in that I felt that my individual phage discovery was a much smaller contribution to science. Further, the relationship I had with a scientific audience who was interested in my research was vastly diminished in the CURE: the purported scientists who were potentially interested in the phage information we uploaded to an online database felt like a nebulous and distant concept, compared to the concrete experience of bringing my findings directly to my faculty research mentor in the apprentice-based research experience. Despite their vast differences, both the CURE and the apprentice-based research experiences made me feel as though I was participating in “real” scientific research.

While the benefits of participating in a CURE are well-established, very little has been done to understand what specific design elements make CUREs feel like “real” research experiences for students. We know that elements of collaboration, iteration, and broadly relevant novel discovery positively contribute to students’ feelings of ownership of the work (Cooper et al., 2019; Corwin et al., 2018), but we do not know if these (or other) CURE design elements help students understand that they are participating in authentic research and increase student buy-in, or motivation to engage in the research experience. Identifying these elements could help educators implement CUREs while amplifying student buy-in, which is linked both to increased student engagement and course performance (Cavanagh et al., 2016).

To explore student perceptions of the authenticity of participating in a CURE, we developed our own independent CURE within the introductory biology curriculum at Portland State University. We worked with Dr. Jason Podrabsky, a biology faculty member at Portland State, to develop curriculum aligned with his research program: students designed iterative experiments to test the biotic and abiotic factors that could induce developmental arrest in the embryos of a species of annual killifish. In addition to helping design the curriculum, I taught two pilot CURE lab sections as a graduate teaching assistant (GTA). While very exciting, the CURE, at times, felt like a disaster. The vast majority of embryos died before students were able to set up their experiments. Embryos continued to die at a high rate throughout the experiment, such that most students did not have a single living embryo at the end of their experiments, while the “lucky” students had two or three. Students ultimately were unable to draw any meaningful conclusions from their experiments.

For most students, this CURE was their very first exposure to scientific research, and I expected them to be frustrated and disappointed by their experience, as I was at times. To my surprise, their reactions were the opposite. Through analyzing written student reflections about their experiences in the CURE, we found that their experiences of failure, while a little disappointing, were also stimulating and exciting. Because they were doing experiments that had never before been done, and attempting to address a meaningful research question, students often interpreted the technical failures as evidence that their experience was “real” research. Students described that in their previous biology lab experiences, failing to achieve an outcome was demoralizing, often because it was an indication that they had done something wrong. However, in the CURE, because they had potential for broadly relevant novel discovery, they interpreted their failure as permissible and described that they imagined it was similar to the experience of being a "real" scientist (Goodwin et al., 2021). **This work is detailed in Chapter 2.**

After presenting our findings about students' interpretations of their experiences with failure at a national conference, I received several questions about how I, as the instructor, must have primed students for the experience of failure: perhaps students only experienced the failure as a positive experience because I had talked them through these experiences. This was, in fact, accurate. As a GTA for the killifish CURE, I was highly invested in the project. I had helped design the course in a way that would allow students to experience the five essential elements of a CURE, and I was conscientious of facilitating these elements for my students. For me, part of my role as a GTA instructor was to help students understand how the work they were doing in the CURE was real scientific research, to teach students the process and nature of scientific research, and to build their competency and autonomy as researchers. In reality, I was more invested in the CURE and in teaching generally than many of my graduate student peers. Yet if universities continue to expand CUREs in their general biology lab curriculum, many GTAs would be expected to teach using this pedagogy, regardless of their interest in doing so or willingness to invest in making the experience as "authentic" as possible for their students.

The expectations of an instructor of a CURE are different from the expectations of an instructor of a traditional laboratory course: rather than delivering content or walking students through the structured instructions of a lab manual, CURE instructors take on an expanded role as a research mentor for their students (Auchincloss et al., 2014; Shortlidge et al., 2016). This role requires a shift in the responsibilities and expectations of TAs who are asked to teach CUREs. A known barrier to such a change occurs when the existing beliefs of instructors are antagonistic to the instructional practice they are expected to adopt (Henderson et al., 2011). I therefore shifted my research focus to understanding the experiences of graduate teaching assistants in adopting evidence-based teaching (EBT) pedagogies, such as CUREs.

To begin this work, I analyzed transcripts from interviews conducted with 32 biology graduate students from institutions nationwide about their experiences and perceptions with adopting EBT pedagogies **(as outlined in Chapter 3)**. Guided by the Diffusion of Innovations model (Rogers, 2003), we mapped the progress each graduate student had made in adopting EBT. We found that while graduate students in our study sample were enthusiastic about evidence-based teaching, many had not actually adopted EBT practices, due either to a lack of training or perceptions that these practices were incompatible with the curriculum. Graduate students—even those who are enthusiastic about EBT—may therefore need additional support and guidance, not just in learning about evidence-based teaching, but in implementing these practices in their classrooms.

From this work, we hypothesized that even if GTAs are enthusiastic about the idea of integrating CUREs into the undergraduate curriculum, GTAs may struggle with the practicality of teaching a CURE. Further, the relative preparedness (and lack thereof) of an individual GTA with regards to teaching a CURE is likely to impact students of GTA-taught CUREs.

I entered grad school with some insight of the potential issues of using GTAs to teach CUREs: after finishing my undergraduate degree, I taught for three years as a "professional" TA, where I taught both the SEA-PHAGES CURE curriculum and a second, microbiology-centered CURE curriculum. At the time, the faculty instructors in charge of the CURE curriculum deliberately avoided using GTAs as CURE instructors in favor of hiring recent graduates—like myself—who had participated and excelled in the CURE curriculum as undergraduates. Because they had experienced the entire curriculum first-hand as an undergraduate student, professional non-student TAs had a solid understanding of the research background, intentions and project flow in the CURE. Further, non-student GTAs were enthusiastic and often willing to invest time and effort in their teaching—often a perceived barrier for graduate students, who are encultured with the belief that research should be prioritized over teaching during their graduate studies (Austin, 2002; Luft et al., 2004; Shortlidge & Eddy, 2018). Of course, for many institutions, hiring non-student TAs instead of GTAs to teach CUREs at a large scale is not financially feasible. It is also not ideal for graduate students, who develop improved research skills and experience professional development benefits while teaching (Austin, 2002; Feldon et al., 2011).

To investigate the impacts of using GTAs to teach CUREs, we used a multiple case study research design at a research-intensive institution in the Pacific Northwest, where GTA-taught CUREs are integrated into the introductory biology curriculum using the SEA-PHAGES model. As part of the case study, we interviewed GTAs about their perceptions and experiences as CURE research mentors (**Chapter 4**). Guided by Expectancy-Value Theory (Wigfield & Eccles, 2000), we explored the type of value a GTA may have for a CURE, and how their value and expectancy of their ability to teach impacts their motivation to invest in teaching the CURE. We found that most GTAs valued teaching the CURE curriculum, and additionally felt they were well-prepared to teach it. However, some GTAs additionally perceived high costs associated with teaching the CURE. We also explored how GTAs conceive of their mentorship role in teaching a CURE and found variation in GTAs' approach to providing either emotional support and/or research mentorship for their students.

As part of the same case study, we examined how variation among GTAs impacted their students' experiences in the CURE **(Chapter 5)**. We used multiple data sources, including in-class focus groups, worksheets, and surveys, to explore how undergraduate students perceived the learning environment created by their GTA, and how their GTA impacted student perceptions of experiencing critical elements of research in the CURE. We identified patterns such that students of certain GTAs reported that their instructor created supportive and comfortable learning environments, while students of other GTAs experienced uncomfortable and sometimes hostile learning environments. GTAs also appear to impact student perceptions of the purpose of participating in the CURE curriculum. These findings provide evidence that different GTAs can significantly impact the way their students experience the curriculum. Finally, both GTAs and students perceived that the SEA-PHAGES CURE lacked the element of broadly relevant novel discovery, suggesting that this curriculum may provide students with an experience more akin to an inquiry-driven laboratory course rather than a true CURE.

As a final component to the case study, we considered how student perceptions of the supportiveness of their GTA impacts student motivation and experiences in the CURE **(Chapter 6)**. We conducted 25 interviews with students who had been taught by the nine different GTA instructors, and used Self-Determination Theory (Ryan & Deci, 2000) to explore student perceptions of their GTA's support for student's competency, autonomy, and relatedness (or sense of belonging) in the CURE. We found that students who perceived that their GTA was unsupportive were less likely to experience high autonomous motivation in the CURE. Further, students who were highly motivated in the CURE were more likely to report experiencing the critical research elements offered in a CURE. We also found that students who failed to successfully isolate their own novel phage reported that the experience of failure decreased their intrinsic motivation in the class. This contradicts our findings from Chapter 2, where students in a CURE described that failure, in the context of broadly relevant novel discovery, did not detract from their overall experience in the CURE. Paired with the perceived lack of broadly relevant novel discovery reported by both students and GTAs (Chapter 5), we interpret students' decreased motivation after experiencing failure in the SEA-PHAGES curriculum as further evidence that this curriculum may not sufficiently foster broadly relevant novel discovery, and therefore may not provide students with the full experience of a CURE.

Together, this work highlights the importance of broadly relevant novel discovery in a CURE, as this element appears to mitigate students' experiences of failure in a CURE. We also find that while GTAs may value evidence-based teaching in general, and the CURE pedagogy specifically, GTAs may need additional support in implementing these pedagogies effectively. Individual GTAs, who vary in their capacity to teach a CURE, can impact their students' experiences and motivation to engage in that CURE.

Summary of Chapters

In Chapter 2, I explore students' perceptions of what makes a CURE feel like an authentic research experience. We find that failure, in the context of broadly relevant novel discovery, can be critical in advancing perceptions of experiencing authentic research.

In Chapter 3, I explore the perceptions and experiences of graduate students with regards to adopting evidence-based teaching practices. We find that while graduate students may be generally enthusiastic about evidence-based teaching, many struggle with implementing evidence-based teaching practices.

In Chapters 4, 5, and 6, I describe findings from a case study designed to explore the perceptions of GTAs teaching a CURE and the impacts of GTA-taught CUREs for students. In Chapter 4, we find that while GTAs generally value the CURE pedagogical approach, they vary in the way they interpret their role as a CURE mentor. In Chapter 5, we find that students can have significantly different experiences and perceptions of a CURE, depending on their GTA. In Chapter 6, we find that students who perceive their GTA is unsupportive are less likely to be motivated to engage in the CURE, and that students with low motivation are less likely to perceive experiencing the critical research elements embedded within the CURE curriculum.

In Chapter 7, I discuss the broader implications of this work, both for researchers and educators.

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Chapter 2

Is this Science? Students' Experiences of Failure Make a Research-Based Course Feel Authentic

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Abstract

Course-based Undergraduate Research Experiences (CUREs) and inquiry-based curriculum both expose students to the scientific process. CUREs additionally engage students in novel and scientifically relevant research, with the intention of providing an "authentic" research experience. However, we have little understanding of which course design elements impact students' beliefs that they are experiencing "authentic" research. We designed a study to explore introductory biology student perceptions of research authenticity in CURE and inquiry classes. Using the Laboratory Course Assessment Survey, we found that students in CURE sections (n=45) perceived higher levels of three authentic research elements (*Collaboration, Relevant Discovery*, and *Iteration*) than students in inquiry-based sections (n=201; *t*-tests, all $p<0.01$). To identify specific factors that impact perceptions of research authenticity, we administered weekly reflection questions to CURE students (n=74). Coding of reflection responses revealed that experiences of failure (59%), iteration (36%), using scientific practices (35%), and the relevant discovery of their project (30%) enhanced students' perceived authenticity of their research experience. Although failure and iteration can occur in both CUREs and inquiry-

based curricula, our findings indicate these experiences—in conjunction with the *Relevant Discovery* element of a CURE—may be particularly powerful in enhancing student perceptions of research authenticity in a CURE.

Introduction

Undergraduate research experiences have the potential to increase student motivation, interest, and retention in Science, Technology, Engineering, and Mathematics (STEM) fields—particularly for students who are traditionally underrepresented in the sciences (Eagan et al., 2013; Laursen et al., 2010; National Academies of Sciences & Medicine, 2015). Universities have therefore been tasked with increasing opportunities for STEM students to participate in these often-transformative research experiences (Bangera & Brownell, 2014; Brewer & Smith, 2011; PCAST, 2012). However, many students do not have the option or ability to participate in traditional research apprenticeships due to various constraints (Bangera & Brownell, 2014), leading to increasing efforts to integrate discovery-based courses into the curricula itself (National Academies of Sciences & Medicine, 2015). Such courses are thought to be particularly impactful for students at the introductory level— the point at which many students leave their STEM degree path (Graham et al., 2013).

Intentionally engaging students in their own learning can positively impact student outcomes such as exam performance and student buy-in (Cavanagh et al., 2016; Freeman et al., 2014). Buy-in can manifest both in endorsement and in attitudes towards active learning, and has been linked to increased engagement and improved course performance (Cavanagh et al., 2016). Further, student recognition that authentic research elements have been integrated into their courses can result in an increased interest and motivation by students to do research (Vereijken et al., 2016, 2019). Thus, student buy-in to the authenticity of a research experience may have the potential to increase engagement, motivation, and performance. One goal of developing discovery-based curricula should therefore be engaging students in a research experience that is authentic—both from the perspective of the educator and (potentially more importantly) of the students.

Designing research-based curricula raises the question: What should an authentic research experience in an undergraduate course look like? Research in the space of an undergraduate classroom may look inherently different than research performed by a research scientist, in that it is inevitably constrained by the structural elements of a course, such as class schedule, equipment availability, cost of course materials, and finite length of the academic term (Bakshi et al., 2016; Govindan et al., 2020; Shortlidge et al., 2016; Spell et al., 2014; Thompson et al., 2016). These constraints necessitate redefining what "authentic" research looks like when adapted for the classroom. Previous research aims to define research authenticity in the space of a science classroom from the perspective of educators and education researchers (Rowland et al., 2016; Spell et al., 2014), and representatives of the Course-based Undergraduate Research Experiences Network (CURE.net) met in 2013 to create a defining framework for elements inherent to course-based undergraduate research experiences (Auchincloss et al., 2014). However, efforts to date to define what authentic research practices look like have focused on the perspective of experts, rather than the perceptions of students. It is unclear which (if any) design elements of courses facilitate students believing that what they are doing in their lab course is “authentic” research, and if those perspectives align with the course designer’s intended outcomes (Corwin, Runyon, et al., 2015). Unpacking the elements that allow students to buy-in to the authenticity of their lab courses will deepen our understanding of the elements that make research-based curricula a valuable experience for undergraduate STEM students.

Expert perceptions of authenticity: Is science a product or a process?

While this study explores student perceptions of research authenticity in the classroom, we aim to frame our work within the diverse beliefs that educators hold regarding course design elements inherent to classroom-based scientific research. Rowland et al. (2016) compiled papers from the research literature where authors (often STEM education researchers) provided their own definition of what makes for “authentic science” in educational contexts. They analyzed 26 definitions of research authenticity, and found that the top reported elements (according to the researchers) included: experiencing the process and practice of science (15 of 26 definitions), ownership/personal relevance to students (7 of 26), engaging students in experimental design (6 of 26) and novel/publishable results and communication (both found in 4 of 26 definitions) (Rowland et al., 2016).

As described in Rowland et al. (2016), some researchers suggest that there are two modes of thinking about authentic research in the classroom: 1) science as a “product”, and 2) science as a “process.” For example, in a national survey of introductory biology lab instructors, researchers found that faculty tend to gravitate to one of two distinct conceptions of authentic research in the classroom—one in which students have the goal of addressing novel questions and generating novel results (the "products" of science), or one in which students experience the process of science by participating in activities such as experimental design and data collection/analysis, without a goal of producing relevant scientific data (Spell et al., 2014). A similar dichotomy is proposed by Barab and Hay (2001), who suggest that authentic research experiences can be either "participatory"—where students actually participate in an expert scientist's research program, and assist in the production of research (working on "products" of science), or "simulated"—where students conduct scientific activities and thereby have the opportunity to simulate being an expert scientist (practicing the "process" of science). There are clear parallels between these two models of authentic research with respect to inquiry and research-based courses in undergraduate biology laboratory classrooms (summarized in Table 2-1).

It is presumptuous to assume that undergraduates—especially those new to research—and experts hold the same beliefs about research authenticity. For example, a multi-institutional study of 665 students and their instructors in 39 different inquiry lab courses found little relation between student and instructor perceptions of what happens in the lab classroom (Beck & Blumer, 2016). Further, it is unlikely that there is a singular context that students will uniformly perceive as "authentic"—Rahm and colleagues argue that the perception of authenticity can "emerge" for different students in different educational contexts (Rahm et al., 2003). It is therefore critical to explore student perceptions of research authenticity in multiple educational contexts where research experiences are fostered, and here we consider both inquiry-based curricula and course-based undergraduate research experiences (CUREs).

Bringing authentic research elements into the classroom

<u>Inquiry-based Courses</u>

The last three decades have seen a large shift in undergraduate biology lab courses replacing cookbook-style labs with discovery-based courses that incorporate elements of inquiry and research into the classroom (Hofstein & Lunetta, 2004; National Academies of Sciences & Medicine, 2015; Sundberg et al., 2005). In cookbook labs, students engage in "confirmatory" activities, where all necessary information is provided to students, there is a "correct" outcome for students, and/or the students are learning a lab technique and essentially following a recipe (Buck et al., 2008; Domin, 1999; Hofstein & Lunetta, 2004). In contrast, inquiry engages students in activities that allow them to develop their own scientific knowledge and understanding of the process of science, through participation in many of the activities that research scientists regularly practice (Domin, 1999; National Research Council, 1996). The label "inquiry" applies to a broad range of course structures and design elements in the context of an undergraduate biology classroom, and there is no singular agreed-upon definition of what an inquiry course looks like (Buck et al., 2008). The relative control that students have over their activities in a given inquiry course can vary greatly, from "structured" inquiry courses, where students are guided through the majority of their work, to "open" inquiry, where students have the autonomy to design their own research methods, collect and analyze data, and communicate their results (Buck et al., 2008). Students in "authentic" inquiry courses may have the opportunity to develop their own research questions, though there is little expectation that students in these courses will produce publication-quality data or ask questions that are novel to the scientific community (Brownell & Kloser, 2015; Buck et al., 2008; Domin, 1999; Spell et al., 2014).

In Table 2-1, we outline our interpretation of how different discovery-based course designs align with the previously described models of authentic research proposed by Barab and Hay (2001) and Spell et al. (2014). When classifying inquiry courses within the context of Barab and Hay's simulated versus participatory authenticity framework, we believe that inquiry-style experiences offer students the chance to *simulate* the experiences of an expert scientist, because students are engaging in the process of science and often have some control over their study design and methods (Barab & Hay, 2001). Inquiry courses may therefore be "authentic" in the sense that students can engage in the same practices of an expert scientist (the "process" of science), even though students are not producing novel and/or relevant data (Spell et al., 2014; Table 2-1).

Course-based Undergraduate Research Experiences (CUREs)

Increasingly prevalent in the literature is a focus on courses where students *do* produce potentially publishable data (for examples, see Auchincloss et al., 2014; Ballen et al., 2017; Corwin, Graham, et al., 2015; National Academies of Sciences & Medicine, 2015; Shortlidge et al., 2016). Involving students in research through a CURE exposes students to the use of multiple *Scientific Practices, Discovery, Broader Relevance, Collaboration*, and *Iteration* (Auchincloss et al., 2014). While students in an inquiry activity may engage in one or more of these practices, the opportunities for novel discoveries that have relevance to the scientific community specifically distinguish CUREs from inquiry courses (Auchincloss et al., 2014; Brownell & Kloser, 2015; Cooper et al., 2017). Recent work has suggested that *Discovery* and *Broader Relevance* are difficult to disentangle in the context of a CURE (see Brownell & Kloser, 2015; Cooper et al., 2019; Corwin, Runyon, et al., 2015). We follow the lead of Cooper et al. (2019) in considering these features as a single item: *Broadly Relevant Novel Discovery,* which we hereon refer to as *Relevant Discovery*.

Like inquiry-based curricula, CUREs vary greatly in design, but generally fall into one of two categories: 1) independent CUREs, often designed by a researcher and/or instructor and frequently based around their research program/interests, which can result in locally or broadly relevant data, or 2) large-scale "network" CUREs, designed for instructors to implement with relative ease (Shortlidge et al., 2017). In both models, students are producing potentially publishable research, though they may have varied control over their research questions and methodological choices (Brownell & Kloser, 2015). Spell and colleagues (2014) cite several examples of independent and network CUREs that emphasize the "science as a product" model of authentic research—where the aim of participating in the CURE is producing or analyzing relevant novel data, and many CURE instructors aim for this outcome (Shortlidge et al., 2016). When the goal of a CURE is students contributing to a larger scientific effort, Barab and Hay's "participatory" rather than "simulated" model of authentic science is emphasized (Barab & Hay, 2001). Within the CURE framework, use of multiple *Scientific Practices, Iteration,* and *Collaboration* represent the "science as a process" model, which students experience in simulated research experiences (Table 2-1). The combination of these "science as a process" elements with *Relevant Discovery* aligns with the model of authenticity that emphasizes the products of science (seeking to answer novel questions and generate relevant results)—a goal of the participatory research model.

Do students buy into the authenticity of their classroom lab experiences?

The educational contexts in which student perceptions of authenticity can emerge could be very different to what experts may perceive to be authentic research experiences (Rahm et al., 2003). Indeed, students in both CURE and inquiry courses use the words "real," "actual," and "genuine" to describe their experiences (Rowland et al., 2016), indicating that students may perceive their experience to be authentic regardless of whether they are participating in scientific research or simulating the scientific process (Barab & Hay, 2001).

There is little research into the specific activities that promote undergraduate students' perceptions of participating in authentic research. A study of nearly 300 high school students who participated in either dry-lab (using a database to explore questions about factors that could influence smoking habits) or wet-lab (using molecular techniques to genotype DNA from human subjects) research found that students in the dry-lab reported participating in a number of scientific activities at a significantly higher level than in the wet-lab, including: coming up with their own research question, testing hypotheses, analyzing data and drawing conclusions. In contrast, students in the wet-lab only reported using the same tools and equipment as scientists do at a significantly higher rate than dry-lab students. Despite the numerous scientific activities that dry-lab students reported participating in compared to wet-lab students, students in the wet-lab had a higher perception that their experience was more similar to what "real scientists" do (Munn et al., 2017). Therefore, simply using scientific tools and equipment—an important component of both inquiry and CURE courses—may be a critical factor impacting students' perceptions that they are participating in "authentic" science.

In this study, we compare how students in a CURE and an inquiry course (hereon referred to as "CURE students" and "inquiry students", respectively) experience authentic research elements in their curriculum, and we identify factors that influence CURE students' perceptions of research authenticity. We quantitatively compare CURE and inquiry students' perceptions of experiencing the different dimensions of research using the CURE framework, with the hypothesis that CURE students will perceive higher levels of *Collaboration*, *Discovery*, and *Iteration*. As CUREs are designed such that students experience both the "process" and "products" of science—both presumed dimensions of authenticity—we developed a series of open-response questions for CURE students to reflect on their course experiences and unpack what contributed to or detracted from the perception that the classroom research experience was authentic. We evaluate our findings of student perceptions of authentic research in relation to how authenticity is described by practitioners in the literature.

Methods

Course Structure and Study Participants

We conducted this study at a large urban public university in the Pacific Northwest, with a largely nontraditional student population with students of various ages and prior college experiences. For this study, we worked with students in the third term of the 200-

level introductory biology for-majors laboratory sequence, during the Spring 2018 academic term. This was a one-unit course associated with a large introductory biology lecture course, and labs were held for three hours per week throughout a ten-week quarter.

There were 21 lab sections led by graduate teaching assistants (GTAs). Students in all lab sections experienced the same conceptual and skill-building labs for the first four weeks of the term. In the remainder of the term, 17 of the lab sections continued with two more typical lab weeks, followed by a four-week inquiry module. These 'inquiry sections' were led by nine GTAs, and involved 373 students. In the inquiry sections, students collaborated in small groups to design behavioral ecology experiments using sowbugs and had the autonomy to develop almost any experiment they wished to execute, given the available time and materials. Students were able to revise or repeat their experiments during the second week of the inquiry module. Students then conducted statistical analyses on both their team data and a larger data set collected from student groups across all inquiry lab sections, and each group designed and presented a PowerPoint presentation of their experiment to their lab section at the end of the term. Students were not graded on the "success" of their experiments but rather on effort and their process of designing experiments and analyzing data to the best of their ability. We categorize this as an inquiry-based course because students developed their own hypotheses and designed their own experiments, but their experiments were not necessarily novel and were not expected to produce potentially-publishable data (Brownell & Kloser, 2015; Buck et al., 2008; Domin, 1999; Spell et al., 2014). Students therefore *simulated* the *process of science,* and experienced *Collaboration* and *Iteration* while using multiple *Scientific Practices* (Table 2-1).

Concurrently, four lab sections participated in a six-week "Killifish CURE" rather than the inquiry sequence. The Killifish CURE lab sections were determined before enrollment opened for the term, and were selected to allow for the CURE sections to run concurrently once a week in the afternoon and the evening to both minimize preparation and to allow the GTAs to assist one another. To control for instructor effect in the associated lecture course, only students enrolled in the larger daytime lecture section were able to enroll in the CURE sections, which was a minimal logistical barrier as two of the CURE lab sections overlapped with the evening lecture. Because self-selection can impact student motivation (Brownell et al., 2013; Rosenthal, 1965), we did not inform students during the enrollment period that certain sections would utilize the CURE curriculum. One week before the beginning of term, students in the CURE lab sections were informed that they were in a special lab section that would allow them to participate in research. Students were therefore able to switch lab sections if they desired. All but one student remained in their originally enrolled lab section. In this way, bias for self-selection into the CURE curriculum was minimized.

The CURE lab sections were led by two GTAs, and involved 87 students. The Killifish CURE was based on a biology faculty member's research program (JEP) and was co-developed with the instructor-of-record for the lecture and lab course, who is a biology faculty member and education researcher (EES). The CURE GTAs (ECG and DEZ) were advisees of the faculty leads, and were closely involved with designing the CURE curriculum. In the Killifish CURE, students designed two iterative rounds of experiments to test which biotic and abiotic factors can induce entrance into diapause (developmental arrest) in the embryos of *Austrofundulus limnaeus*, an annual killifish species that inhabits ephemeral ponds in Venezuela. CURE students participated in a brainstorming activity to develop novel hypotheses and experiments that would build on prior research on the topic, during which the GTAs subtly guided students toward a few pre-determined experimental design options that course instructors believed could lead to potentially-publishable data. Thus, the intention was for students to feel they had some autonomy in developing the research questions and experimental design, and the course instructors were able to ensure that student projects were feasible and could be accommodated at a large scale. Throughout the CURE, students collaborated in small groups, and like the inquiry sections, students had the opportunity to revise, repeat, or expand on their experiments. As with the inquiry sections, student grades were not impacted by the "success" of their experiments.

We designed the CURE to intentionally incorporate all of the CURE elements: *Collaboration, Iteration*, and use of multiple Scientific Practices, all in the context of *Relevant Discovery* (Auchincloss et al., 2014). Our goal was for students to *participate* in faculty-driven research with the goal of *producing* novel and scientifically relevant data (Table 2-1). To scaffold *Relevant Discovery* into our curricula, we had students read a research paper from the faculty killifish researcher (JEP), and showed students a video and pictures highlighting research from the killifish lab to familiarize them with the research program they were contributing to. Both the faculty researcher (JEP) and the instructor-of-record (EES) visited the CURE sections, and students had the opportunity to directly discuss their projects with the faculty researcher and get feedback and advice on their experimental design.

In scaffolding the CURE, we inherently introduced differences between the CURE and inquiry experiences that could impact direct comparisons between the course types, and we have made an effort to highlight these differences throughout this paper to increase transparency of the limitations of this study. For example, while both CURE and inquiry students were asked to do a similar amount of work in their respective labs, and all students worked in groups, CURE students were allowed to submit assignments that they completed as a group, while inquiry students completed their assignments individually. Because the CURE students needed separate lab periods to set up their experiments and collect their data, CURE students spent two more weeks on the CURE project compared to inquiry students, who could complete the entirety of their experiments (set-up and data collection) within a single lab period. The nature of the assignments and assessments in the CURE sections were also slightly different, as they were designed to help students document and understand their experimental design and data collection, analysis, and interpretation. CURE students also answered weekly reflection questions (described below), which could have impacted their perceptions, as they prompted to student to think about their course experiences.

All students enrolled in the labs were recruited to participate in a research study in the first week of the term, and in total 302 inquiry students (81% of total inquiry section enrollment) and 74 CURE students (85% of total CURE section enrollment) consented to be part of the research study. By consenting, students allowed researchers access to course assignments, surveys, institutional information, and their final lab and lecture grades. This study was approved by the university's Institutional Review Board (no. 184544).

Data Collection

We addressed our research questions with an embedded mixed-methods approach, in which we concurrently collected quantitative survey data from both CURE and inquiry students and written reflection responses from CURE students (Creswell, 2009). These data were collected to allow us to compare perceived levels of authentic research elements between the two course designs, and to gain a deeper understanding of how students interpret research authenticity in a classroom setting.

Laboratory Course Assessment Survey

We used the Laboratory Course Assessment Survey (LCAS) (Corwin, Runyon, et al., 2015), a 17-item instrument to measure CURE and inquiry students' perceived levels of experiencing specific authentic research elements in their lab courses. The LCAS has previously been used to detect differences in student experiences across course-types (Cooper et al., 2019; Corwin et al., 2018; Corwin, Runyon, et al., 2015; Esparza et al., 2020), and specifically was designed to measure perceived participation in *Collaboration, Relevant Discovery*, and *Iteration* activities. This allows us to compare student perceptions of both "science as a process" (*Collaboration* and *Iteration*) and "science as a product" activities (*Relevant Discovery*). Students in the inquiry labs were prompted to consider the sowbug experiments in answering the questions, while the CURE students were prompted to consider the killifish experiments. We predicted that CURE students would in general perceive higher levels of *Collaboration*, *Relevant Discovery*, and *Iteration*. We expected that one survey item (*Relevant Discovery* Item 3; "I was expected to formulate my own research questions or hypothesis to guide an investigation") would behave inconsistently with our prediction, since CURE students were guided toward testing research questions that could feasibly lead to novel and potentially publishable data, whereas inquiry students were given carte blanche in forming hypotheses related to sowbug behavior.

The original survey was designed for students on the semester system, but since we are on a quarter system, we modified the response scale options used for the *Collaboration* items to align with a more condensed course schedule. For example, the response option "Monthly" became "A couple of times, but not every lab period." The final version of our survey (Appendix A.1) was reviewed by several undergraduate representatives of our student population and by GTAs of both the CURE and inquiry sections. We disseminated the survey online via Qualtrics to all lab students in the introductory biology course during the last week of the term, and students were offered two points of extra credit for taking the survey. In total, 201 inquiry students (67% of inquiry student participants) responded to the survey, and 45 CURE students (61% of CURE student participants) responded.

<u>CURE Student Reflections</u>

To explore students' beliefs and feelings about participating in the CURE, students were assigned one to three weekly reflection questions as part of their regular quizzes throughout the six-week CURE module. In total, 12 reflection questions were administered to students, and responses were graded by GTAs for completion rather than content. Because we were primarily interested in students' perceptions of research authenticity after they had experience with the CURE, we focused our analysis on nine questions that were administered in the final three weeks of the CURE (Table 2-2).

Data Analysis

<u>LCAS CFAs and *t*-tests</u>

We administered the LCAS to CURE and inquiry lab students to measure perceptions of *Collaboration*, *Relevant Discovery*, and *Iteration*. Although the LCAS was developed and shown to produce valid data at other institutions for use with undergraduate STEM students, different student populations may interpret survey items in unique ways, and even minor modifications to any instrument could impact student responses (Barbera & VandenPlas, 2011). We therefore used confirmatory factor analysis (CFA) to collect evidence of construct validity by testing if the latent construct structure of the instrument functions for our institutional population and course context (Hancock et al., 2018). We specifically tested a correlated three-factor model with *Collaboration*, *Relevant Discovery*, and *Iteration* as separate latent factors (see Appendix A.2). We used a robust maximum likelihood estimator with the Satorra-Bentler correction in all CFAs to correct for potential non-normality in our item responses. While the maximum likelihood estimator assumes a continuous response scale, which is not ideal for data with less than five response categories and will therefore likely underestimate our model fit (Hancock et al., 2018), we chose to proceed with this estimator to maintain continuity with prior studies (e.g. Corwin et al., 2018).

To determine the appropriate statistic to use as an estimate of the internal consistency of our instrument scales, we ran single-factor CFAs for each of the three factors using both a congeneric model (i.e. unrestricted factor loadings) and a tau-equivalent model, where all factor loadings are forced to be equivalent (Komperda, Pentecost, et al., 2018). The omega reliability coefficient is equivalent to Cronbach's alpha when factor loadings are equivalent, but avoids bias introduced by Cronbach's alpha when factor loadings are independent (Komperda, Hosbein, et al., 2018; Komperda, Pentecost, et al., 2018). We therefore report Cronbach's alpha as an estimate for reliability when the data-model fit met our study cutoffs (Confirmatory Fit Index (CFI) and Tucker-Lewis Index (TLI) $\geq$ 0.950, and Root Mean Square Error of Approximation (RMSEA) $\leq$ 0.05, as suggested by Hancock et al. (2018)) under tau-equivalent conditions, and omega total when model fit met the study cutoffs only for the congeneric model.

Item scores for each construct were summed, and we used *t*-tests to test for differences between sum construct scores for inquiry and CURE students and Hedge's *g* to calculate effect size. We also tested for differences between inquiry and CURE students in demographics and lab/lecture grades using chi-square tests of independence for categorical data and *t*-tests for continuous data. Welch's *t*-test was used whenever Bartlett's test for homogeneity of variance indicated that sample variances were unequal. All statistical analyses were conducted in R version 3.6.2, using the base, *lavaan* and *userfriendlyscience* packages (Peters, 2018; R Core Team, 2019; Rosseel, 2012; RStudio Team, 2019).

Qualitative Data Analysis of CURE Reflection Responses

Three researchers (ECG, VA, MJG) reviewed all CURE reflection responses and together established a coding scheme to capture the reoccurring sentiments in the responses. We developed the coding scheme using both *a priori* codes based off of the CURE framework

(*Collaboration, Relevant Discovery, Iteration, and Scientific Practices*) (Auchincloss et al., 2014) and initial structural coding, where we created codes to describe ideas that were arising from the text responses (Saldana, 2015). Each code was a short label that encompassed a specific perception or experience that students described, and was accompanied by a longer definition to clarify the code for the research team. For example, the code "Real Research: Iteration" was defined as: "Iteration, repeating experiments, or doing the experiment over a period of weeks contributes to student perceptions that the CURE was 'real research.'" The coding scheme was organized into thematically similar categories of codes (e.g. *"Factors that contribute to perceptions that CURE is 'real research'"*). While we developed codes that allowed for analysis of all written reflection responses, there were certain code categories that were only relevant to specific sets of questions. Within this work, we focus on code categories regarding student's perceptions about whether their CURE experience felt like "real research." The three researchers coded all reflections independently in small sets, and calculated percent agreement for each set. The final percent agreement for all coding data averaged between the three reviewers was 72%. Percent agreement calculations were used to ensure high coding standards were maintained amongst the team and to facilitate reflexive conversations throughout the coding process, rather than to formally quantify our reliability or divide labor between multiple coders (O'Connor & Joffe, 2020). All three researchers carefully discussed every code designation in all student reflections to consensus.

Results

Demographics and student experiences

We collected institutional data for all study participants, and found that on average, CURE students were slightly older than inquiry students, (CURE mean age = 24.3 years, inquiry mean age = 22.8 years; Welch's t=2.023, df=97.94, p= 0.05). We did not detect any other significant demographic differences between the CURE and inquiry students (chi-square tests of independence, Appendix A.3).

CURE and inquiry student lecture grades did not differ significantly from one another (CURE lecture grade average = 84.9%, inquiry lecture grade average = 86.3%; t = 1.158, p = 0.25). However, CURE students scored on average two percentage points more than inquiry students in the lab (CURE lab grade average = 96.3%, inquiry lab grade average = 94.3%, Welch's t=2.632, p<0.01). This is possibly because of the experimental-focused and collaborative CURE group assignments rather than the individual assignments expected from inquiry students.

CURE Students Perceive Higher Levels of Collaboration, Relevant Discovery, and Iteration

We collected descriptive statistics for each LCAS survey item in order to assess the normality of our data, and found no items that displayed extreme deviations from normality (Appendix A.4). We used a robust estimator in the CFAs to account for any moderate deviations from normality in our data. Single-factor CFAs indicated that omega total is an appropriate reliability statistic for all three scales, and all three scales had high internal consistency (Appendix A.5). As predicted, within the single factor *Relevant Discovery* subscale, Item 3 *("I was expected to formulate my own research questions or hypothesis* *to guide an investigation"*) had a substantially lower factor loading compared to the other *Relevant Discovery* items, and summary statistics (Appendix A.4) indicate a reduced gap between CURE and inquiry students for this item. We discussed our theoretical concerns about this item with one of the LCAS authors and ultimately decided our theoretical and quantitative evidence was sufficient to omit this item from further data analysis with this study population. While the following analyses omit *Relevant Discovery* Item 3, we found that presence or absence of this item has negligible effect on the three-factor model fit and the summed differences between CURE and inquiry students for the *Relevant Discovery* subscale.

We tested the *a priori* correlated three-factor model with *Collaboration*, *Relevant Discovery*, and *Iteration* as separate latent factors (see Appendix A.2). Modification indices indicated a strong correlation between *Iteration* Item 1 (I1) and the *Relevant Discovery* scale, indicating that I1 is not functioning as expected. We hypothesize that this could be due to I1's shared question stem with the *Relevant Discovery* items (Appendix A.1). We therefore removed this item from the final analysis. Fit indices for the final model indicate that it was functioning appropriately for our student population (Table 2-3).

We summed the LCAS scores for each scale, using only the items included in our final model. While students in both CURE and inquiry lab sections perceived relatively high levels of *Collaboration, Relevant Discovery,* and *Iteration*, CURE students reported experiencing significantly higher levels of each construct in their laboratory course (t-tests, $p<0.001$; Figure 2-1, see Table 2-4 for test statistics). The largest effect size between inquiry and CURE students was seen for the *Iteration* scale, though there was also a medium effect size for the *Relevant Discovery* scale. In comparing these observed means for the LCAS factors between CURE and inquiry students we ideally would have first conducted strict measurement invariance tests between the two groups to establish that error variances were similar across groups; however, our CURE student group was too small (N=45) to conduct invariance tests (Rocabado et al., 2020).

CURE students perceive that their research experience is authentic

We coded students' responses to the reflection question "Do you feel that you conducted real scientific research this term?" into three mutually exclusive categories. We found that the majority (76%) of CURE students believed that they conducted real scientific research and provided a variety of justifications for why their experience was 'real', as exemplified by the quote below:

> *"Yes, we did conduct real research. We went into these experiments not knowing what the outcome would be. We also got to design our own experiments. Some of them did not work, but that is how real research goes."*

In total, 18% of CURE students were unsure if they had conducted real scientific research, and often provided thoughtful responses describing limitations they experienced during the course such as:

> *"Maybe we conducted real research. I feel that the sample size in our experiment is too small to be significant."*

Only 7% of students reported that they had not experienced real research in the CURE:

> *"No, I feel like this CURE is too short for real scientific research. It is in a very controlled setting so in a way it does not feel real."*

Several factors enhance the perceived authenticity of the student research experience

In order to understand why students reported their research experience felt real or did not feel real, we coded reflection responses to nine questions administered to students during the last three weeks of the CURE for justifications of student perceptions of research authenticity. On average, students described 1.9 unique reasons (SD=1.2) justifying why they felt their experience was authentic (summarized in Table 2-5). Unexpectedly, we found that experiences of *Failure* were the most cited explanation students provided for why the CURE felt like real research, which was discussed by 59% of CURE students. We refer to *Failure* as experiences where students are unable to successfully carry out a task to achieve a specific goal (Henry et al., 2019). Students in the CURE all experienced failure during the term, as the majority of the killifish embryos they were working with perished, and very few student teams finished the term with interpretable results. Students were not graded on their experimental success, and were able to repeat their experiment to try to achieve clearer results. These students rarely seemed discouraged by their experiences of failure, and sometimes even found them invigorating, as in the quote below:

> *"I love that the experiment did not go as planned—I mean, sure, it is not ideal that a bunch of embryos died, however, this is how real science works. I am usually so bored in the assigned labs… [they] are carefully designed so that students get the "right" answer." (In response to Question 2; see Table 2-2 for question list)*

Although students reflected on their experiences of failure unprompted, we also specifically prompted students in one question to discuss their feelings about the embryo die-off, which could have led to artificially inflated proportions of students using failure as a rationale for why their experience felt real. However, *Failure* clearly resonated with students as they considered the authenticity of their research experience.

Students also reported that experiencing *Iteration* (36.5%) contributed to their perception that they were participating in real research. Many students explained that experiencing *Iteration* throughout their multiweek lab experience allowed them to understand that scientific research was not necessarily a quick and easy process:

> *"In the [regular] lab typically we would just spend a couple of hours studying something, but real research is done over time. I realize now it can be very repetitive." (In response to Question 6)*

Experiencing *Scientific Practices*, using scientific tools, or participating in the scientific process (36.5%) was a frequently cited explanation of why students felt their experience was authentic. Statements that this code applied to were often straightforward, and frequently alluded to the scientific method or listed scientific activities, as in the quote below:

> *"I think we conducted real scientific research in this class because we ran a real experiment like researchers do. We follow-up step-by-step on the rules needed for an experiment like: creating a hypothesis, setting up a control, following up on the parameter every week and analyzing data." (In response to Question 4)*

Students also discussed experiencing *Autonomy*, or the sense of project ownership, and creativity that they perceived to be a part of real science (22%). In their discussions of autonomy, students often described an increased appreciation for scientific research and for the CURE itself, as they felt they were expected to think more independently and realized that there was not always one "right" answer both specifically in their course, and in science in general. For example:

> *"The main perception that changed was the amount of 'freedom' and 'creativity' you're allowed to have when doing scientific research. I thought that you would have stricter guidelines to conducting experiments. However, as a researcher the way you conduct your experiments is entirely up to you, and there are many different ways to determine the answer you*

are looking for. I was happy to discover that scientific research encourages creativity." (In response to Question 6)

Relevant Discovery (29.7%) and *Collaboration* with teammates (12%) also contributed to students' perceptions that research felt real. While students frequently mentioned the faculty researcher whose research program was the focus of the CURE, these were almost exclusively in reference to the increased awareness of the potential for *Relevant Discovery* within the CURE:

"I appreciated when [the faculty researcher] went into greater detail about the relevance of the experiment. It's easy to just focus on the basic aspects of the experiment like they're just a one-shot lab intended to teach a concept. Placing this in a larger picture with a large, unanswered question was cool." (In response to Question 1)

We therefore coded these instances as "*Relevant Discovery*" rather than "*Collaboration.*" Interacting with the faculty researcher seemingly had a powerful effect on student discussions of *Relevant Discovery* —64% of students who indicated that *Relevant Discovery* made their course feel like real research connected this at least in part to interacting with the faculty researcher. While *Collaboration* as defined in the CURE literature can include collaboration with teammates, researchers, and instructors (Auchincloss et al., 2014), students did not reflect on collaborating with their lab instructors, and we therefore coded *Collaboration* exclusively when students indicated working with their teammates:

"I have come to the realization that research is often a team effort, and collaboration is one of the most important parts." (In response to Question 6)

Finally, only 3% of students described that experiencing *“Successful” Science* was the reason that their lab experience felt like “real research”, as exemplified in the quote below:

> *“I feel like we did (conduct real scientific research); we actually got several embryos to enter diapause so that was a win! Not everything was ruined by the embryonic deaths.” (In response to Question 4)*

Very few students ended the term with sufficient sample sizes to conduct statistical analyses that could robustly address their hypotheses, so it is unsurprising that few students discussed the success of their experiments in lab.

Similar experiences can have variable impacts on student perceptions of research authenticity

We coded the same set of reflection responses with an eye for identifying aspects of the experience that may have detracted from the perceived authenticity of the CURE. These statements were much less prevalent, and on average, students described only 0.4 unique course elements (SD=0.6) that made their experience feel inauthentic. Student critiques of how their experiences deviated from an authentic research experience were thoughtful and often fair assessments of the limitations of the CURE; for example, 9% of students discussed the lack of time to continue their experiments:

> *“It is unfortunate that we do not have a longer period of time for data collection. I feel that more time would allow for more conclusive results to be drawn, due to the number of experimental conditions that had to be changed and the low rate of survival experienced with embryos.” (In response to Question 4)*

Other elements students provided that made the course feel less authentic included a lack of significant results (12%) and a relative lack of autonomy (7%) (Table 2-6). Many of the reasons provided for why their experience felt inauthentic mirrored reasons other students cited as authentic research elements (Figure 2-2). For example, while most students (59%) interpreted their experiences of failure as a natural part of research, 4% of students interpreted those same experimental failures as indicators that they had *not* participated in "real" research:

> *"Overall, I feel like I did not conduct real scientific research this term… For Experiment 1, 6 embryos were alive, and potentially in diapause. However, in week 2, they all died. With Experiment 2, after adjusting our treatment, all 28 embryos died. With this, our group could not perform any type of statistical test." (In response to Question 4)*

Similarly, while many students perceived that their opportunities for iteration (36%), use of scientific practices (35%), and autonomy (22%) over their experiments made their experiences feel real, other students felt that their experience was not real because of insufficient iteration (9%), use of scientific practices (4%), or autonomy (7%).

Discussion

CURE students perceive higher levels of Collaboration, Relevant Discovery, and Iteration

In this study, we first aimed to quantitatively compare student perceptions of specific authentic research elements in two different lab types: a CURE and an inquiry-based course. We measured student perceptions of *Collaboration, Relevant Discovery,* and *Iteration*. Although both CURE and inquiry students recognized high levels of these elements in their laboratory course, CURE students perceived statistically higher levels of each element. Notably, the effect size for the difference between perceived *Collaboration* was relatively small, which makes sense given that CURE and inquiry students both collaborated in small and similarly-structured groups. If we consider that *Collaboration, Relevant Discovery,* and *Iteration* are components of an authentic research experience, these results offer some clarification to the few previous attempts to compare CURE and inquiry student perceptions of research authenticity in the literature. Rowland and colleagues (2016) found that both CURE and inquiry students describe their experiences as "real," and our results suggest that while this may be true, CURE students may still perceive higher degrees of authenticity in their laboratory experiences. This supports recent findings that CURE students agree more strongly with the statement that they conducted scientific research in their lab course than students who experienced lab curricula that lacked *Relevant Discovery* (Cooper et al., 2019).

CURE students in particular reported higher perceived levels of *Iteration* compared to the inquiry students, which is notable given that both CURE and inquiry students iterated their experiments twice. CURE students conducted their experiments over a longer period of time (6 weeks compared to 4 weeks) and the instructors and faculty killifish researcher (JEP) worked with CURE students to plan their second experimental iteration with great intentionality, to help students build off what they had learned from their first experimental attempt. Although CURE students scored higher than inquiry students on each item within the LCAS *Iteration* subscale, CURE students reported particularly high perceived opportunities to revise their analyses and presentations based on feedback (LCAS items I5 and I6; Appendix A.4). CURE students did not have more opportunities for formal formative feedback, so these items may reflect potentially increased attention that CURE instructors gave to their students in iterating their experiments and interpreting their results. Due to these efforts, CURE students may have had a better understanding and placed more value on the opportunity for *Iteration*. This aligns with previous evidence that students in research-based courses may develop an improved understanding of the nature of science: a large-scale qualitative study found that undergraduates in traditional, inquiry, and research-based labs had similar basic conceptions of different aspects of the nature of science, but inquiry and research-based students were able to articulate their understanding of the nature of science with respectively increased sophistication (Russell & Weaver, 2011).

Experiencing elements of the process of science within the context of "participatory" research may be key to student perceptions of research authenticity

In Table 2-1, we proposed that CUREs align with a "participatory" model of authentic research, where *Relevant Discovery* and pursuing the "products" of science are prioritized (Auchincloss et al., 2014; Barab & Hay, 2001; Spell et al., 2014). However, in analyzing CURE student reflections to understand how different aspects of their experiences impact their perceptions of research authenticity, we found that *Relevant Discovery* was only the fourth most prevalent factor that students reported contributing to the authenticity of their experience. Rather, students most commonly described experiencing *Failure* as making their experience feel "real." We define failure as the inability to achieve a specific goal: these experiences were more serious than easily-rectified errors, but also did not discourage students from persisting in redesigning and repeating their CURE research projects (Henry et al., 2019). The top three elements contributing to perceived authenticity (experiencing *Failure*, *Iteration*, and *Scientific*

Practices) all are arguably "process" of science elements that could occur in either simulated (inquiry) or participatory (CURE) models of authentic research. However, student reflections often indicated that experiences of failure were powerful in the CURE because the lack of a predetermined experimental scheme and expectations to confirm a previously tested hypothesis made failure feel inherently acceptable in the course. While teaching the CURE, instructors deliberately held discussions with students about how their experiences of challenges and failure are experiences inherent to scientific research, so it is unsurprising to see this perception mirrored in the student reflections. Additionally, the lack of performance-based goals and normalization of failure within our CURE likely served to reduce student stress and encourage "adaptive academic coping" behaviors, which are predicted to foster resiliency and challenge-seeking behaviors in students (Henry et al., 2019). CURE student reflections also displayed an understanding that collecting reliable data was important in order to contribute to addressing the novel killifish research question, and that time, patience, and *Iteration* are necessary components to producing reliable data.

These findings mirror those of Gin et al (2018), who found that students in a "high-challenge" course where CURE students mostly failed to "successfully" answer their research question responded more positively to their repeated experiences of iteration than students in a parallel "low-challenge" course. Further, students in the "high-challenge" course reported experiencing the same outcomes as students who did not experience as much failure or iteration in their course, indicating that failure and iteration did not detract from the positive benefits of CURE participation. Rather, they found that the context of

Relevant Discovery that was inherent to the course design motivated students who experienced challenges, and likely elevated the perceived importance of *Iteration* for students (Gin et al., 2018).

From these observations, we propose that while failure and iteration could occur in either simulated (inquiry) or participatory (CURE) models of authentic research, these elements are particularly powerful for students who are engaged in a participatory model of research and experience *Relevant Discovery*. This hypothesis is supported by the survey data, where CURE students reported higher levels of *Iteration* compared to inquiry students, despite both curricula offering opportunities for *Iteration*. In other words, the context of the CURE may promote student buy-in to the authenticity of their research experience to a greater extent than "simulating" research in an inquiry course, though CURE students may still prioritize the "process" of science elements that are common to both CURE and inquiry courses when considering the authenticity of their research experience. By increasing student buy-in during research-based courses through experiences of *Iteration*, *Failure*, and *Relevant Discovery*, we may also increase student engagement in learning and performance (Cavanagh et al., 2016).

Alignment of Student and Expert Perceptions of Authentic Research

We compared how student perceptions of which research elements made their experiences feel "real" with both the CURE constructs and with expert definitions of real research (Table 2-7). Although failure was the top explanation students gave for why their research felt "real", this research element is not present in either the expert definitions of research (compiled in Rowland et al., 2016) or in the originally proposed CURE constructs

(Auchincloss et al., 2014). Failure may therefore be a critical and previously-underestimated experience for undergraduates in research-based courses. In light of this, researchers and curriculum designers may want to focus their attention on framing and studying experiences of failure, as colleagues have begun to with the "Failure as a part of Learning: A Mindset Education network (FLAMEnet)" initiative (Heemstra et al., n.d.).

The remaining elements that students identified as components of an authentic research experience were also recognized in at least one source by experts as an authentic research element. *Iteration* is included within the original CURE framework, but not in the expert definitions compiled by Rowland et al., 2016. Use of multiple *Scientific Practices, Relevant Discovery,* and *Collaboration* were elements of authenticity agreed on by students and experts—these elements were present in Rowland's compiled expert definitions of research authenticity and in the original CURE constructs. Finally, nearly a quarter of the CURE students discussed the importance of student autonomy, ownership, or creative license in supporting the perceived authenticity of their experience. Although ownership is not a part of the original CURE framework, there have been several previous suggestions that ownership or autonomy is important in creating an authentic research experience for students (Barab & Hay, 2001; D. I. Hanauer et al., 2012; Rahm et al., 2003; Rowland et al., 2016; Wald & Harland, 2017), and particularly in CUREs (Cooper et al., 2019; Gin et al., 2018; Hanauer & Dolan, 2014).

Intriguingly, many of the experiences that the majority of students reported contributing to their perceptions of authentic research triggered the opposite conclusion for a minority of students. For example, while most found that failure and the opportunity for iteration made their experience feel more real, a few reasoned that their failures and the lack of time for increased iteration was what detracted from the authenticity of their research experience. Recent research has suggested that while failure can be a productive experience for undergraduates in a CURE (Gin et al., 2018), and CURE instructors view opportunities for students to deal with failure as beneficial for students (Shortlidge & Brownell, 2016), experiencing failure in research can also be a factor in exacerbating depression for apprentice-based undergraduate researchers (Cooper et al., 2020). We join Cooper et al (2020) in hypothesizing that student researchers' variable perceptions of failure, and of other elements in our CURE, could be due to student mindset: students with a growth mindset may interpret challenges as productive learning experiences, while students with a fixed mindset tend to give up easily and respond negatively to setbacks (Dweck, 2008; Henry et al., 2019). In our CURE, instructor-led discussions about the normalcy of failure in scientific research likely contributed to the majority of students recognizing failure as an experience to be expected when conducting scientific research. Because of the variable ways that students may interpret these experiences, instructors should be deliberate in normalizing failure and carefully framing these experiences for their students, in order to promote productive student learning experiences and a growth-mindset.

Student reflections provide content validity evidence supporting CURE Framework

The CURE framework as proposed by Auchincloss and colleagues (2014) was derived through discussions from a small group of people experienced with CURE instruction and assessment, who aimed to outline the elements necessary to engage students in research within the space of a course. To our knowledge, the degree to which the CURE framework elements lead to a perceived "authentic" experience for undergraduate students has not been externally validated by the target population. Through our work, we are able to test if the aspects that make a CURE feel like "research" to the target population (undergraduate students) converge with the expert-defined CURE framework. Although our reflection questions did not directly probe students about the CURE framework elements, we found that each element—*Iteration,* use of multiple *Scientific Practices*, *Collaboration*, and *Relevant Discovery*—was present in student descriptions of what made their research experience feel authentic. These data indicate that intentionally scaffolding each of these elements, in conjunction with providing students with opportunities for *Failure* and *Autonomy*, will best support CURE students in perceiving that they are participating in real research.

Limitations

There are several limitations to this study, in particular with regards to our attempts to compare the experiences of inquiry and CURE students. The inquiry and CURE courses occurred concurrently and engaged students from the same student population, but there were some differences to the curricula that could have variable impacts on the perceptions that CURE and inquiry students had of their experiences. The CURE and inquiry project study organisms were very different—CURE students worked with fish and their embryos, while inquiry students worked with sowbugs. Although we do not have data on this, we anecdotally have observed a range of student reactions to working with both of these study organisms, including disgust and boredom (esp. sowbugs), squeamishness and excitement to be working with living organisms (both sowbugs and killifish), and enthrallment, particularly for killifish. These perceptions and attitudes may affect student interest and motivation in engaging with the course (Hidi & Renninger, 2006), which could ultimately be reflected in the way students respond in the survey and reflection questions they completed for this study.

CURE students spent an additional two weeks on their work, and the additional time likely allowed the GTAs to spend more time providing in-class formative feedback to their students. In combination with the study reflection questions, this could have aided the CURE students in thinking more deeply about their experience. Our qualitative data was self-reported by our student participants through reflection questions that would be read by their GTAs, and this context could potentially lead to bias in student responses, though we tried to mitigate this by making it clear that the reflection questions were not graded for content. While the sample size from our CURE students is sufficient to provide us with extensive qualitative information, we had limited resources to scale-up the CURE to more laboratory sections, and therefore lack the sample size needed to conduct more statistically appropriate quantitative comparisons between CURE and inquiry students. Further, while we initially chose to focus our qualitative data collection on CURE students who would be able to report their experiences with both "process" and "product" of science elements, in retrospect we would have extended this study by administering similar reflection questions to both CURE and inquiry students, in order to further explore the differences and similarities in how CURE and inquiry students operationalize research authenticity in their classrooms. Our plans to expand data collection in subsequent terms to increase our statistical power and comparisons between CURE and inquiry students were thwarted by 1) a collapse of our Killifish study system in Spring 2019, and 2) the COVID-19 pandemic in Spring 2020.

Finally, our data is only representative of one introductory biology university population and may not be representative of student experiences in other institutional contexts, particularly given the relatively high proportions of transfer, nontraditionally-aged, and postbaccalaureate students within our study population. Although a previous study with our student population found that student age or postbaccalaureate status did not have much impact on student perceptions of the classroom (Shortlidge et al., 2019), older students are more likely to endorse learning-oriented rather than performance goals, and are therefore likely to have a stronger growth mindset and resiliency to failure (Dweck, 2008; Eppler et al., 2000). The relatively high proportion of nontraditionally-aged students within our student population is therefore an unexplored potential explanation for our student's positive reaction to failure in the CURE.

Conclusion

Overall, we found that the majority of students who participated in a novel Killifish CURE believed they were indeed participating in real research, and we found significant overlap between expert and student explanations of what constitutes an authentic research experience. Interestingly, CURE students largely attributed experiences of failure and iteration to why they felt they had participated in real research. Therefore, if instructors of discovery-based courses aim for students to believe that they are participating in real research, they may want to consider how to leverage and positively facilitate these experiences in curriculum design in order to promote student buy-in.

As educators and researchers, we often believe that research experiences are beneficial for students. However, we don't know how important it is for students to believe they are experiencing real research in order to reap the benefits of research participation. We propose that future research explores whether students need to "buy in" to the authenticity of their research experience in order to benefit from their exposure to research. Further, if students do need to believe that their research experience is authentic in order to experience the benefits of research participation, do their perceptions of research authenticity need to align with the expert expectations and beliefs of what makes a classroom research experience authentic? This work contributes to our growing understanding of student perceptions of evidence-based teaching, and of the value of how discovery-based curricula can offer more equitable access to authentic research experiences.

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Figures and Tables

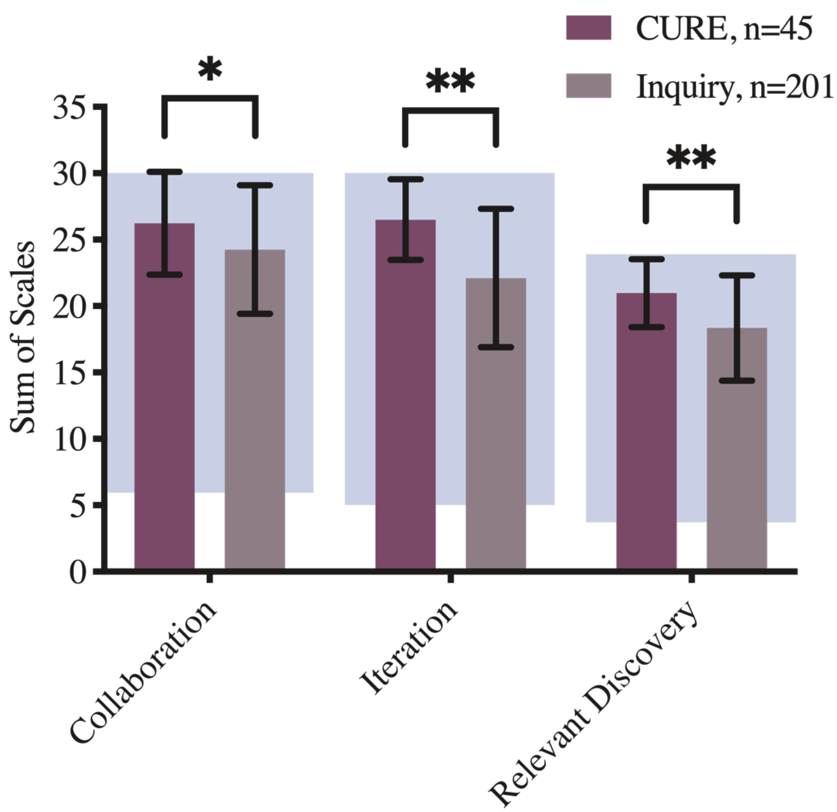

Figure 2-1. *CURE students perceive significantly higher levels of essential CURE constructs*

*CURE students perceive significantly higher Collaboration, Relevant Discovery and Iteration compared to their inquiry peers, as indicated by higher numbers for each scale (t-tests, * indicates p<0.05, ** indicates p<0.001; see Table 2-4 for test statistics). Background shading indicates potential score range of each summed scale: Relevant Discovery and Iteration were measured on a six-point Likert scale, while Collaboration was measured on a 5-point Likert scale. Bars represent data mean ± SD.*

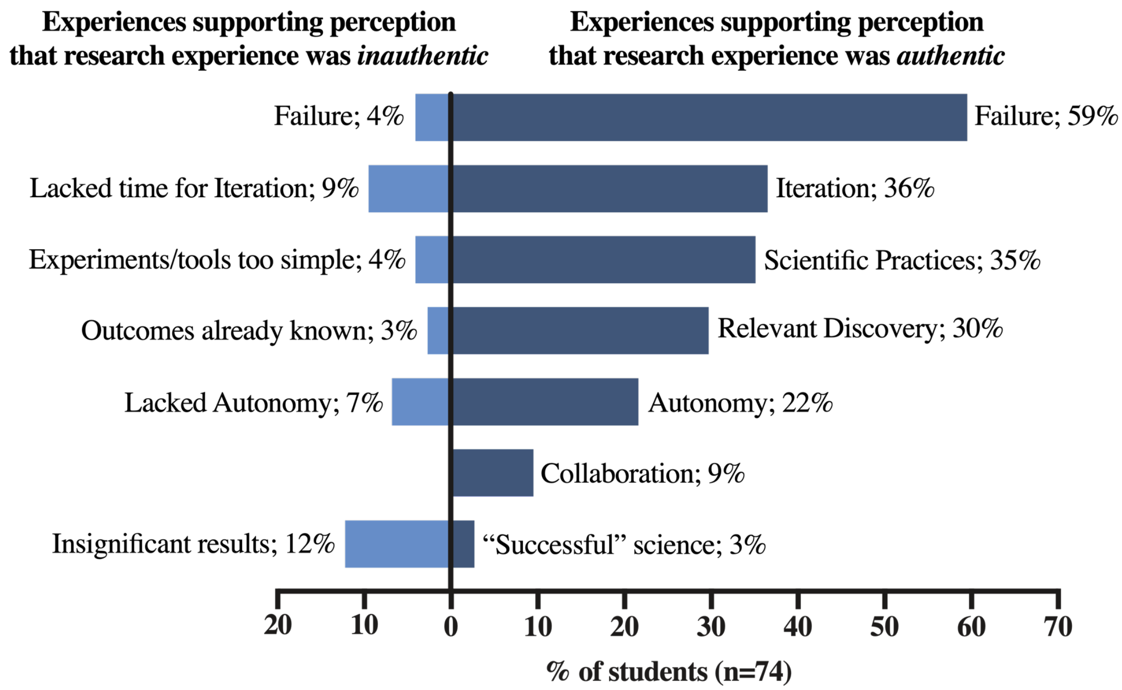

Figure 2-2. *Parallel factors contributing to the CURE student's perceptions that their research experience was authentic or inauthentic*

Table 2-1. *Alignment of Inquiry and CURE models with existing frameworks of authentic research in the science lab*

Authenticity Framework	Inquiry	CUREs
Authenticity can be *Simulated* or *Participatory* (Barab & Hay, 2001)	Students **simulate** the activities of an expert researcher	Students **participate** in an expert's research project
Authentic research includes the *Process* or *Products* (Novel Questions/Results) of science (Spell et al., 2014)	Prioritizes that students experience the **process of science** over answering novel questions	Prioritizes that students seek to generate **novel results (products of science)** over experiencing the process of science
CURE Research Dimensions (Auchincloss et al., 2014)	Students may engage in **Scientific Practices, Collaboration,** and **Iteration**	Students engage in novel **Relevant Discovery** in addition to Scientific Practices, Collaboration, and Iteration

Table 2-2. *CURE Student Reflection Questions*

CURE Context	Question ID	Question Text
Week 4 *Students completed data collection and analysis from Experiment 1, and monitored progress of Experiment 2.*	1	Last week the researcher who directs our CURE project stopped by to check in on your experimental progress. Were your interactions valuable? Why or why not?
	2	Last week our embryos did not develop as quickly as we were expecting and many unexpectedly died. How do you feel about the fact that we had to make last minute changes to our experimental plan?
	3	What has been the most challenging aspect of this course so far for you?
Week 5 *Students completed data collection and analysis from Experiment 2.*	4	Do you feel that you conducted real scientific research in lab this term? Why or why not?
	5	Do you see yourself as a scientist and/or a person who utilizes scientific principles and practices in your daily life? Please explain why/why not.
	6	Have your perceptions of what it means to do scientific research changed due to participating in the CURE portion of this lab course? If so, what has changed?
Week 6 *Students presented their CURE projects to class.*	7	If you had the opportunity to spend five more weeks in this lab, what would you want to do or learn with the extended time?
	8	Until this CURE, most of your previous introductory biology lab experiences involved lab activities that did not extend beyond a single lab period. Were there any difficulties or frustrations you faced due to the multi-week structure of the CURE lab project? Which format do you prefer?
	9	What skills that you practiced in this course were new to you? Describe the most useful skill you learned from this course, and why it is valuable to you.

Table 2-3. *Fit indices for LCAS Confirmatory Factor Analysis*

Fit Indices	Data-Model Fit	Accepted Cutoff*
CFI	0.977	≥ 0.950
TLI	0.972	≥ 0.950
RMSEA (90% confidence)	0.047 (0.024-0.066)	≤ 0.050

*As suggested by (Hancock et al., 2018)

Table 2-4. *LCAS Collaboration, Iteration, and Relevant Discovery scores for CURE and inquiry students*

		Inquiry students n=201		CURE students n=45					
Scale	Score range	Mean	SD	Mean	SD	Welch *df* [a]	*t*	*p*	Hedge's *g* [b]
Collaboration	6-30	24.26	4.83	26.24	3.87	*NA*	2.58	0.011	0.42
Iteration	5-30	22.10	5.21	26.51	3.04	110.31	7.56	<0.001	0.90
Relevant Discovery	4-24	18.36	3.97	20.98	2.55	98.02	5.55	<0.001	0.70

[a]Welch's degrees of freedom were only used when the assumption of homogeneity of variance between inquiry and CURE students was not met (Bartlett's test) (Dalgaard, 2008). [b] Effect size reference values are arbitrary, but in general a small effect size is below 0.5, a medium effect size is between 0.5 and 0.8, and a large effect size is greater than 0.8 (Hancock et al., 2018).

Table 2-5. *Coded elements that contributed to students' perception that their research experience was "real."*

"Real" Research Codes	Example Quote*
Failure: Experiencing failure or setbacks	I always thought scientific research always runs smoothly or everything usually goes as planned. This made me realize that it's a lot of work to conduct scientific research and [experiments] don't run perfectly. There are always going to be some flaws or some negative outcomes. *(In response to Question 6)*
Iteration: Repeating experiments, or doing the experiment over a period of weeks	I prefer [the CURE] lab because it is more like real research... In this format we are able to trace the experiment for weeks and we have this opportunity to figure out the problems, and finally the [end] result is more reliable. *(In response to Question 8)*
Scientific practices: Using the practices, methods, tools, or processes of science	I have learned that scientific research is different than what I was expecting. I thought it was all theories and proving them. However, it's a technique and a deep research on identifying relevant data, and gathering it, and testing the hypothesis using a scientific method, and studying each change on the subject. *(In response to Question 6)*
Relevant Discovery: The potential for novel scientific discovery and/or the relevance of the project to the scientific community	To actually meet the person we're doing this research for really changes our perspectives. Being able to ask him questions on a personal level validates the point and purpose of why we're even doing it. *(In response to Question 1)*
Autonomy: Having autonomy, project ownership, or creative license (including in experimental design and interpreting results)	There are no real set guidelines [in research] since you are trying to "discover" something. You actually face trial and errors and try to find a solution to rectify this problem which was cool to see. It's great to actually use my own brain for once and try to figure out the data I am collecting and what it means. *(In response to Question 6)*
Collaboration: Working with classmates on their research project	I somewhat feel like I did [conduct real research] because I am working together with my teammates to figure out how to do a specific task in order to get the result we want to see. We all worked together to brainstorm and when our experiment failed, we would try to figure something else that could work better. *(In response to Question 4)*
"Successful" science: Producing data or results, experiencing success in experiments, or answering research questions	I do feel as if I have conducted real scientific research in this term of biology lab. The goal was to try to simulate an environment where the embryos would enter into diapause I, and my group was successful in doing so. Although having another species with the embryos might not be the exact and only reason that the embryos went into diapause I, it is a step closer to the right answer, or it may be part of the factors to the right answer. *(In response to Question 4)*

* Quotes have been lightly edited for grammar and concision. Question list is available in Table 2.

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Chapter 3

Catching the Wave: Are Biology Graduate Students on Board with Evidence-Based Teaching?

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Abstract

Graduate students hold a critical role in responding to national calls for increased adoption of evidence-based teaching (EBT) in undergraduate classrooms, as they not only serve as teaching assistants, but also represent the pool from which future faculty will emerge. Through interviews with 32 biology graduate students from 25 institutions nationwide, we sought to understand the progress these graduate students are making in adopting EBT through qualitative exploration of their perceptions of and experiences with both EBT and instructional professional development. Initial inductive content analysis of interview transcripts guided the holistic placement of participants within stages of Roger's Diffusions of Innovations model, which we use as a theoretical framework to describe the progress of EBT adoption. We found that most graduate students in our sample are aware of and value EBT, but only 37.5% have implemented EBT. Many who were progressing towards EBT adoption had sought out supplementary instructional experiences beyond the requirements of their programs, and 72% perceived an institutional lack of support for teaching-related professional development opportunities. These data indicate that while

many graduate students are already engaged with the movement to adopt EBT, graduate training programs should emphasize increasing access to quality training in EBT strategies.

Introduction

Two principal actions are required to respond to the national calls for increasing retention and building equity in undergraduate science classrooms (Brewer & Smith, 2011; PCAST, 2012). First, we must determine and evaluate the classroom strategies that can be used to reach these goals, and second, facilitate the widespread dissemination of these strategies into undergraduate classrooms. Much progress has been made to develop evidence-based teaching (EBT) strategies that can be used to better reach our students. These strategies are typically student-centered and based on research that tests their effectiveness (e.g., clickers, Socratic discussion, case studies) (Handelsman et al., 2004; Tanner, 2013). For those who might be interested in adopting EBT, there is little doubt left that these active learning strategies are working for many students. In addition to reports of affective gains such as positive impacts on student motivation, self-esteem, and attitude (Cleveland et al., 2017; Michael, 2006; Springer et al., 1999), a meta-analysis of 225 individual studies found that active learning increases examination scores and decreases failure rates (Freeman et al., 2014). As we continue to develop and evaluate active learning strategies, significant attention must also be given to efforts to increase dissemination of EBT into undergraduate classrooms.

In many biology departments, graduate student teaching assistants (TAs) teach laboratory and discussion sections for high-enrollment introductory courses—in a survey given to 34 research universities, 91% reported that biology graduate students are responsible for most of the laboratory instruction (Sundberg et al., 2005). Because graduate student TAs may end up with more undergraduate face-time than faculty, and graduate students represent the pool of future faculty, there have been proposals advocating for improvement in pedagogical training for graduate students (Austin, 2002; Gardner & Jones, 2011; Kendall et al., 2013; Reeves et al., 2016; Rushin et al., 1997). A framework for TA instructional professional development by Reeves et al. (2016), describes how a TA's pedagogical knowledge, attitudes, and beliefs impact their teaching practices, which in-turn directly impacts undergraduate students. Further, there is a suite of contextual variables such as the institution type, the training TAs have been exposed to, and the preexisting teaching experience, attitudes, and career aspirations of TAs (Reeves et al., 2016) that influence how a TA operates in the classroom. Understanding the experiences, attitudes, and perceptions that graduate students have towards EBT will build a better understanding of the variables that impact graduate student adoption of EBT.

Instructor Adoption of EBT

To date, studies on instructor adoption of new teaching strategies have focused on faculty rather than graduate students. Simply sharing the "evidence" behind EBT does not seem to be enough to incite adoption of EBT among science faculty; for example, interviews with physics faculty revealed a mistrust of physics education research and education researchers (Henderson & Dancy, 2008). Similarly, biology faculty prioritize their personal experiences of success over education research as rationale for sustained adoption of case-study teaching (Andrews & Lemons, 2015). This indicates that faculty likely need more structure and support to successfully adopt EBT—informing instructors that specific strategies "work" is likely insufficient.

Further, the propensity towards adoption of EBT is likely highly context-specific. A study of science faculty at one research institution revealed that faculty across scientific disciplines have high awareness of specific EBT strategies, but levels of interest and rates of adoption of EBT strategies vary greatly between faculty in different departments (Lund & Stains, 2015). Such differences were thought to be caused by differences in departments, learning environments, personal experiences, and attitudes towards teaching. Given the different contextual influences faculty and graduate students are exposed to, it would be negligent to assume that graduate students approach EBT with the same attitudes, beliefs, and goals as faculty. It is therefore vitally important to understand not only how faculty perceive EBT, but graduate students as well, if we are to best facilitate adoption of EBT in the newest generation of biology faculty.

Potential factors impacting graduate student adoption of EBTs

The professional identity of scientists often tends to value and prioritize research over teaching, which could be a significant barrier to adoption of evidence-based teaching (Brownell & Tanner 2012). While many faculty have already formed their professional identity as a scientist, graduate students are only beginning to develop a professional identity, and may therefore be more receptive to making changes to their teaching practices. However, graduate students also have less autonomy in the classroom than faculty instructors—a 2002 case study of graduate TAs at a single UK university found that TAs were dissatisfied with their lack of freedom in their teaching (Park & Ramos, 2002). While their dissatisfaction with their lack of freedom indicates the possibility that graduate students could desire more flexibility to experiment in teaching, the perception that they do not have the autonomy to adapt the material or alter their teaching style could hinder EBT adoption.

Even if graduate students have some level of autonomy in the classroom, adoption of EBT strategies, as for faculty, is likely to be largely context-dependent and subject to influences from departments, advisors, and perceptions of their own role as graduate students. In contrast to current faculty, who may have had limited personal experiences with EBT as undergraduates, graduate students may already be familiar with EBT from their time as undergraduates, which could impact their attitudes towards EBT. For example, interviews with six chemistry TAs revealed that their own frustrating experiences as undergraduates in inquiry courses led them to be hesitant that inquiry-based instruction was suitable for their students (Kurdziel et al., 2003). Indeed, most research on TA experiences with using EBT have focused specifically on inquiry-based laboratory instruction, and have found that graduate students, at least initially, struggle and are frustrated with inquiry-based instruction (Gormally et al., 2016; Kurdziel et al., 2003; Mutambuki & Schwartz, 2018). This may be due to a struggle to align the teaching method with their perceptions of effective teaching—for example, graduate students who prioritize the importance of content knowledge may have difficulty valuing inquiry-style teaching (Kurdziel et al., 2003; Luft et al., 2004). These values and perceptions of EBT strategies will impact graduate students' approaches to teaching and their decisions to adopt EBT.

In order to better understand if and how graduate students, specifically those in the life sciences, are gaining experiences with evidence-based teaching strategies, and whether they are interested in and prepared to adopt EBT strategies as a regular part of their teaching, we conducted a qualitative study. We specifically sought to learn:

1. What types of teaching experiences or training are graduate students expected or required to participate in? Do graduate students perceive that their programs support them in gaining training and experience using EBT strategies?
2. Do graduate students know about evidence-based teaching strategies and the shift in academic culture that values evidence-based teaching?
3. Are graduate students adopting or interested in adopting EBT strategies, and are there factors that correspond with EBT adoption?

Theoretical Framework

Roger's Diffusion of Innovations (DOI) model has been used to describe faculty adoption of EBT (Andrews & Lemons, 2015; Henderson et al., 2012; Henderson & Dancy, 2008; Lund & Stains, 2015), shedding light upon where the barriers to EBT adoption lie. DOI is a theoretical framework first published in 1962 that describes the process a motivated individual or organization takes in deciding to adopt an innovation (Rogers, 2003). The model was initially developed to describe the adoption of agricultural innovations by farmers (Rogers, 2003), and has since been used to describe the adoption (or lack of adoption) of many innovations ranging from information systems (Bhattacherjee, 2001) to evidence-based practices in healthcare (Dobbins et al., 2002; Kajermo et al., 1998). According to the DOI framework, the individual adopting an innovation goes through several steps: first they gain knowledge of an innovation (Stage 1, *Knowledge*), then develop a positive or negative attitude towards that innovation (Stage

2, *Persuasion*). Next, they engage in activities that lead to a decision on whether or not to implement the innovation themselves (Stage 3, *Decision*). The individual then implements the innovation (Stage 4, *Implementation*), and finally reflects on whether or not to continue use of the innovation (Stage 5, *Confirmation*). These steps can happen over years or rapidly, and they are not strictly linear—for example, an individual could engage in a training session (*Decision*), during which they might both learn about an innovation (*Knowledge*) and form an opinion (*Persuasion*).

Because we started with little knowledge of the teaching-related perceptions and experiences of current biology graduate students, we chose to use qualitative research methods to begin to gain an in-depth understanding of our subjects, far beyond what could be accomplished through a survey instrument (Creswell, 2009). Given the admirable prior usage of the DOI model and the nature of our data, we chose to also use the DOI framework to identify the stages of our study participants in adoption of EBT. Using this lens, we can delve into the perceptions and experiences of graduate students who both successfully adopt and fail to adopt EBT. The nature of the model will also allow us to gain insights into where graduate student adoption of EBT is commonly delayed.

Methods

Participant recruitment

We recruited interview participants through a link at the end of the Life Sciences Graduate Student Survey (LSGSS). The LSGSS was an online survey that aimed to gain an understanding of life science graduate student experiences with evidence-based teaching strategies. We sent the survey to graduate students nationwide in the summer of 2016 through various listservs and snowball sampling. At the end of the survey, participants were given the option to follow a link to a new form allowing them to volunteer their contact information for a possible follow-up interview. We invited all 148 participants who provided their contact information to participate in interviews, and received 38 responses to our interview request. Of these volunteers, 32 signed up for and completed the interview process. The information in the LSGSS and the interviews discussed in this study were not linked; therefore, we derived all information presented in this study directly from the interviews, and online survey results are presented elsewhere (Shortlidge & Eddy, 2018). We used nationwide survey data of life sciences graduate students and recent doctoral recipients from National Science Foundation surveys (*Survey of Earned Doctorates,* 2016; *Survey of Graduate Students and Postdoctorates in Science and Engineering,* 2016) to identify demographics of US life science graduate students. We then used chi-square goodness of fit tests to calculate if the reported race, gender, and university type of our participants was representative of graduate students nationwide. The Portland State Internal Review Board approved this study (Protocol #163844).

Interview design and execution

The interview protocol consisted of 17 questions primarily intended to explore participants' experiences with and perceptions of evidence-based teaching strategies. Participants were asked about professional development they received within their graduate programs, and their self-efficacy as an instructor. The interview protocol concluded with 10 optional demographic questions (Appendix B.1). All participants were interviewed via *Skype* by a single researcher. Prior to beginning the interviews, the research team discussed the purpose of each question and conducted pilot interviews with several graduate students in the life sciences who were not connected to the study. We used these validity efforts to confirm that the questions were appropriately designed to prompt productive discussion of graduate student experiences, and to verify that graduate students interpreted the questions in the manner intended. The interviews were semi-structured (Cohen & Crabtree, 2006), therefore the interviewer could deviate from the scripted interview to ask follow-up questions for clarification or elaboration. The interviews lasted 30 minutes on average, were audio-recorded, transcribed verbatim (*Rev.com, San Francisco*), and de-identified prior to data analysis.

Data Analysis

Three researchers read all of the interview transcripts and independently created lists of the different perceptions, attitudes, and opinions that arose from participant responses throughout the interviews. Together, we discussed our initial findings from the interviews, and developed a comprehensive preliminary list of "codes." These codes were short, descriptive phrases that could be used to describe particular perceptions, attitudes, or opinions expressed by the participants throughout the transcript text. As different questions evoked diverse responses from participants, the developed codes were not necessarily linked to responses to specific interview questions. In order to refine our list of codes and confirm that we independently understood how to use each code, we methodically re-read four interview transcripts that we felt represented diverse participant perspectives, and independently made notations of where we felt the codes should be applied. We then convened to discuss our coding decisions, and reflected as a group on the ways in which specific codes were either useful, or unclear and/or redundant. Using the notes from the group discussion, a single researcher reduced and reorganized the list of codes into a preliminary codebook. Two researchers then used the codebook to independently code 2-3 transcripts at a time, and we reconvened between each set to discuss and further define and reduce codes in our codebook that were unclear to us. We intentionally selected transcripts that reflected diverse perspectives to use for this process, and in total, we used 14 transcripts in the process of refining our codebook. We considered the codebook to be robust once two of us were able to use the final version to code six (19%) of the transcripts with an averaged 83% interrater reliability (Madill et al., 2000). A single researcher then used the final codebook to re-code all of the transcripts that had not yet been coded with the final codebook, conferring with another researcher when the coding designation was ambiguous or difficult to discern. All coding with the final codebook was conducted using NVivo (v. 11.4, QSR International). Participant information that was quantitative or categorical (e.g., year in program, type of teaching training) was recorded directly into a spreadsheet. Analysis of coding considered only the presence or absence of specific themes within each participant's interview, not the frequency in which a single participant expressed a particular theme.

For a final check of coding accuracy, two additional researchers uninvolved in the initial coding or the codebook development audited the data derived from the interview transcripts. To prepare for this audit, the researchers read all of the interview transcripts, were debriefed in detail on the project, and were trained to use the codebook. We recorded all resulting data for each individual participant, which included: categorical variables (e.g., institution type), numeric data (e.g., number of courses taught), and if the participant made a statement pertaining to each code (presence/absence of code) in a master spreadsheet. From this spreadsheet, we randomly generated a list of cells to audit (10% of the data; specifically, 500 of 5056 cells), which were divided between the auditors, who worked independently to confirm the presence or absence of selected data by rereading the original transcripts. For example, if the randomly selected cell showed that the participant had made a statement represented by a particular code in the codebook, those data were verified through reading the text of the corresponding transcript and identifying if that participant did indeed make at least one statement that could be coded under the specific theme. In nearly all instances, auditors agreed with the initial coding.

During coding, it became apparent that there were overarching themes in the attitudes and beliefs of the participants that, while frequently associated with specific codes, were not always sufficiently described by the codes. The primary coder and two auditors re-read all of the interview transcripts, and discussed which participants exhibited specific attitudes or beliefs based off of the entire interview text. We used these holistic targeted evaluations to elucidate each participants' placement within the DOI model: the entire research team discussed how participants would be placed into the DOI model, and final placements were determined through iterative and collaborative discussions involving at least three researchers. To understand if a graduate students' placement along the DOI model could potentially be influenced by their career goals, field of study, or time in program, we informally observed trends in these categories once all participants were placed on the DOI model, however, due to the low sample size and the qualitative nature of this study, we do not present statistical differences among groups of participants.

Results

Participant demographics

In total, 32 life sciences graduate students from 25 different institutions across the continental United States were interviewed. The majority (69%) of the participants attended highest research activity (R1) universities, with the remainder from higher research institutions (R2, 19%), moderate research institutions (R3, 9%), and Special Focus institutions (3%) (*The Carnegie Classification of Institutions of Higher Education*). Participants ranged in age from 23 to 40 years old (mean = 28.6 years, SD = 3.5). The majority of the participants identified as female (59%); 75% as White/Caucasian, 13% Asian American, 9% Latina/o, and 3% identified as Indian. There were no significant differences (chi-square goodness-of-fit, all $p>0.05$) between our sample's reported demographics (gender, race/ethnicity, and university type) and those reported in the NSF 2016 *Survey of Earned Doctorates* and the *Survey of Graduate Students and Postdoctorates in Science and Engineering.*

Graduate student status and professional goals

Overall, 97% of our participants were PhD students, and all participants were at least in the 2^{nd} year of their graduate programs (mean year in program = 4.3; SD = 1.3). Participants were conducting graduate research on topics that spanned sub-disciplines of biology: 37.5% molecular or cellular biology, genetics or immunology; 34% ecology; 16%

evolutionary biology; and 12.5% biology education research (BER). Additionally, 9% of the students who had a non-BER research focus self-reported participating to some extent in an education research project in addition to their primary research projects. We considered that graduate students who had participated in BER may have a biased awareness of evidence-based teaching strategies that would not be representative of life science graduate students in general. Upon reflection and discussion of the interview transcripts as well as statistical tests for differences among BER students and/or those who had participated in education research, the research team determined that their experiences did not differ from that of their peers who had not been involved in education research. Therefore, these data include graduate students studying both basic biology research and biology education research.

Participants reported being interested in pursuing a varied set of professional goals: 28% hope to obtain primarily research positions in academia; 31% explicitly stated they want to obtain an academic position that would allow them to balance both research and teaching responsibilities; and 19% were interested in primarily teaching positions. The remaining 22% described plans to leave academia for careers in government, industry, or science communication and outreach.

Graduate students receive little support towards instructional training

To address our first research question, we report on our participants' experiences with teaching, mandatory TA training, and their perceptions regarding their program's support towards their instructional training. Our participants had diverse experiences in their roles as TAs. The majority were experienced TAs—19% had one term of TA experience, 44% had between two and five terms experience, and 31% had between six and 14 terms of experience as a TA. Only 6% of the participants had never been a TA before. Most of the participants had experience teaching lab sections (72%) and/or recitation sections (63%); however, 19% had experience as the instructor of record for a course. A few participants did not provide a specific count of the number of terms of TA experience they had, thus the reported terms of TA experience are conservative estimates based on the information provided. For example, one participant explained:

> *"I've taught a lot of different classes. I've taught Plant Ecology, Introductory Biology, Genetics, and right now I'm teaching a Botany class." (Male, 3rd year Ecology PhD student)*

This student did not specify if they had taught multiple iterations of any of the four classes they listed; therefore, we recorded that they only had 4 terms of TA experience.

Most graduate students participate in some form of mandatory TA training

We felt it was important to understand what mandatory training our participants had received from their universities with regards to their teaching responsibilities, and if their training had included information about EBT strategies. Only 28% of our participants described taking a required TA training course that lasted a full term, while 47% described participating in a "boot camp" style TA training either before or concurrently with their first term as a teaching assistant (Figure 3-1A).

While we were encouraged that 75% of our participants had received some formal mandatory training through a course or boot camp, 46% of those who had received formal training reported that they were not given any instruction in the use of any teaching strategies (Figure 3-1B). An additional 29% of those with formal training described receiving very little training in instructional strategies—described by one participant through the following statement:

> *"It's mostly not really about teaching strategies but mostly, how to identify sexual harassment and those sorts of things. They do tell you some of the strategies out there, but they don't really emphasize them that much." (Male, 5th year Ecology PhD student)*

Only 12.5% of graduate students reported that they had received substantial training in the use of various instructional strategies in their formal mandatory training, for example:

> *"We also had an opportunity to present for five minutes to practice teaching and then also a period later on where it was 15 minutes practice teaching... It's kind of neat to see other people teach. We also talked about some teaching strategies and active learning strategies." (Female, 2nd year Cellular Biology PhD student)*

Graduate students perceive a lack of support to develop instructional skills

In total, 72% of our participants discussed the various deficits in their opportunities to develop their instructional skills within their programs. Some graduate students (28%) additionally highlighted the disparity between the lack of these opportunities and their department's proclaimed value for teaching (Table 3-1).

The most commonly-described deficit of instructional development was *limited instructional training* (44%). Although some of these participants explained that they did not have access to any instructional training, many who perceived *limited instructional training* simply felt that the training they did receive was insufficient. Others who perceived *limited instructional training* at their institution were aware of optional training, but described barriers that prevented them from taking advantage of these opportunities—they had no incentives to go to attend, or even felt pressure from peers or advisors to not spend time on instructional training at the cost of forfeiting time that should be spent on research. For example:

> *"I'm not sure how many students actually take those optional (teaching) courses but perhaps (the department should) advertise those a little bit more. I personally don't know anybody who's actually taken those courses yet." (Male, 2nd year Ecology PhD student)*

Similarly, participants who expressed that they had *limited opportunities to teach* (34%) both described logistical limitations (primarily limited teaching opportunities at their institutions) or a lack of support from peers and advisors towards pursuing teaching opportunities simply for the sake of gaining experience as an instructor, rather than the necessity of receiving financial support from a TAship:

> *"I really wanted to do more teaching and basically everybody told me to stop doing that… it would be nice if there was a little more support for people who wanted to teach more." (Female, 4th year Evolutionary Biology PhD student).*

A third of the participants (all who had at least some opportunities to teach) perceived a deficit of instructional professional development, reporting they had *limited opportunities to expand their teaching role (34%)*. A couple of these participants repeatedly taught the same class, and felt that the challenge of teaching a different type of course (i.e. course content, a majors vs non-majors class, or anything other than a lab section) would further develop their instructional skills. Other participants in this group expressed that a standard TA-ship, where they were provided with materials and constrained expectations for what needs to happen in their classroom, is insufficient for fully preparing them as instructors:

> *"For me a huge (challenge) is going to be actually teaching a full course… I really need to be able to put all the pieces together. Including the teaching strategies, developing lesson plans, doing the assessments, because that*

> *I've never done before, putting it all together." (Female, 5th year Molecular Biology PhD student)*

These graduate students desired the opportunities to develop teaching materials, to experience giving large lectures, or to fully design and teach an undergraduate course.

A smaller but compelling group of graduate students described situations in which they perceived that their institution provided *lip service towards valuing teaching* (28%), explaining or giving examples in which their institution attempted to give the appearance of valuing teaching, but in practice did not sufficiently support graduate students in learning how to teach. For example, some students described that their institutions technically provided institutional training, but that it was a highly insufficient effort to actually develop their instructional skills. Some of these students expressed incredulity that their programs expected them to develop instructional skills in their training, either due to the lack of informative instructional skills emphasized in the training, or to the minimal nature of the training (one as short as 15 minutes: *"I think there was (training)… It was like a 15-minute, couple of slides at our grad student orientation. That was it." Female, 5th year Ecology PhD student*). Other participants perceived negative attitudes from their peers and faculty within their department towards the instructional opportunities offered, and explained that many in their department considered instructional training activities were "blow-off" or "useless" pursuits.

Graduate students are aware of the academic culture shift favoring evidence-based teaching

Perhaps surprisingly, in investigating our second research question we found that our participants exhibited a high level of awareness and appreciation for EBT strategies

(Table 3-2). In total, 84% of our sample conveyed that they *value evidence-based teaching strategies.* Many of these participants demonstrated their value of EBT strategies by both explaining why they find evidence-based strategies to be more effective through their experiences either as a student or an instructor, and by simply describing the active learning strategies that they preferred over didactic lecture.

Demonstrating their interest in and commitment to gaining instructional experience, 59% of participants sought out non-mandatory teaching opportunities. These participants found opportunities to attend teaching-centric workshops or classes, to give guest lectures, and to teach extra classes or develop course materials for the purpose of gaining instructional experiences. Many of these participants described these non-mandatory opportunities as the experiences that allowed them to further learn and practice implementation of EBT strategies.

Graduate students were also aware of the increasing value that universities and education research places on EBT, which we describe as participants perceiving the *changing landscape of academia in teaching* (78%). Graduate students who perceived this shift in academia described observing a trend in increased use of EBT, and perceived that universities are increasingly expecting EBT to be used in their classrooms:

> *"It seems like even at larger state schools, there's a greater focus on student-centered learning, active learning, nontraditional classrooms, group work in a more transformative way. It's become much more important at a variety of institutions." (Male, 5th year Ecology PhD student)*

A smaller subset of this group (47% of participants) fell into a group that explicitly exhibited self-awareness of their own role in this shift towards valuing EBT strategies (*part of the changing landscape of academia*). These participants repeatedly used first-person language that conveyed personal accountability for promoting attitude shifts and adoption in favor of EBT strategies within their departments and fields. Further, these participants often described the specific changes they had made (or planned to make) to their own teaching in order to advance the use of EBT within their discipline, or described specific interactions with their peers and/or actions they had taken within their departments in support and promotion of EBT adoption.

Graduate students are interested in adopting evidence-based teaching strategies

To address our third research question, we mapped the progress of graduate students in adopting EBT strategies using the DOI model. As we used our codebook to identify the major themes present in these interviews, we also were able to identify that certain themes and holistic trends correlated to groups of graduate students who were in different stages of the process of incorporating EBT strategies into their teaching philosophies. For each stage in the model, we mapped the proportion of the 32 participants who successfully "continue" through each stage and the proportion who fall out of the adoption process (Figure 3-2). Here we describe characteristics of groups of participants who arrived at each stage of the model. For clarity, we will continue to use percentages to describe proportions of our total participants who fall into the different DOI stages, but proportions of small sub-groups presenting specific characteristics within each DOI stage will be described numerically.

Stage 1, *Knowledge:* Most graduate students know about EBT

Knowledge of an innovation is the stage when an individual learns of the existence of the innovation, which can be impacted by the individual's socioeconomic status, personality, communication behavior, and access to relevant communication channels (Rogers, 2003). For graduate students, communication channels that lead to knowledge of EBT strategies could include professional development events and courses, their research advisors, instructors and lab managers for the courses they TA in, and peers. Graduate students in our study exhibited a wide range in their level of knowledge of EBT strategies, and were accustomed to an assortment of different terminology to describe EBT. We specifically asked students about their familiarity with student-centered teaching practices versus instructor-centered teaching practices (Appendix B.1), and for those who asked for a definition of student-centered teaching practices, we described the contrast between didactic lecturing versus putting more responsibility for learning on students through active learning strategies. We considered participants who exhibited understanding of evidence-based strategies throughout their interviews to have *Knowledge* about EBT, for example:

> *"Student-centered learning is the idea is that the students are taking a much more active role in their own education… stuff like doing hands-on activities or doing the research on a particular topic or leading a discussion." (Female, 5th year Genetics PhD student)*

Participants who were unfamiliar with EBT strategies, even with the help of an explanation, stopped progressing towards adoption of EBT strategies at the *Knowledge* stage.

Most of our participants (84%) had an accurate working definition of student-centered teaching (or active learning), and were at minimum familiar with at least one or two specific strategies. Nearly all of these participants who have knowledge of EBTs moved on to the second stage in the model, and only one participant remained at this stage in the model—they were aware of EBTs, but ambivalent in their attitude towards them.

Some participants (12.5%) lacked a clear conception of evidence-based teaching strategies, even when prompted with definitions and/or examples, which prevented them from truly beginning the process of adopting EBT. Intriguingly, participants in this group did express some interest in the concept of engaging students. For example, one participant indicated that they wanted to design an "interactive" class, but could not communicate how they would facilitate that:

> *Participant: With Introductory Biology, it's really much more of a lecture type setting, but I would try to make it to where it was a little bit interactive, when you were asking students questions.*
>
> *Interviewer: Do you have ideas how you might facilitate that interaction?*
>
> *Participant: I don't think I do specifically. For labs, I'll ask questions, and then it's ... Labs are always very much obviously interactive. I don't think I have so much of an idea for a classroom setting. (Male, 3rd year Ecology PhD student)*

While their lack of awareness about EBT strategies prevented them from progressing through the model, it is encouraging that this group appears like they would be open to the idea of learning about EBT.

Stage 2, *Persuasion:* Most graduate students have positive attitudes towards EBT

At the *Persuasion* stage, graduate students formed a positive or negative attitude regarding the use of evidence-based teaching strategies. All participants who had formed positive attitudes towards EBT strategies (75%) progressed to the *Decision* stage of the DOI model. For example:

> *"One of the shortcomings I see in our current way we do higher education in the sciences is so much of it is just canned stuff, where it's come in, do this lab, listen to this. Getting more active inquiry, working through things, working through problems, and actually seeing the process of science in*

action, I think would be a good thing for the field as a whole." (Male, 5th year Ecology PhD student)

A few participants who were aware of EBT strategies had a negative attitude towards them (9%), therefore dropping out of the process of adopting EBT strategies at the *Persuasion* stage (Figure 3-2). These students felt that there were opportunities within their departments to develop their teaching skills, but they were not interested in pursuing them:

> *"I would say that I'm more prepared to be a research faculty member. I could do the teaching as well, but considering I've personally prepared myself to be a researcher, that's where it is. If I wanted to prepare myself to be a better teaching faculty member, I could have said to my advisor, "I want to TA every semester", which would have increased my experiences. I would have had that opportunity if I wanted to." (Male, 4th year Molecular Biology PhD student)*

Unsurprisingly, these participants also unanimously did not think there would not be much of a benefit towards learning about EBT:

> *"I have those things that I took away from undergrad that I enjoyed, and the things I didn't enjoy. I feel like between a mesh of all that, I wouldn't change too much." (Male, 2nd year Evolutionary Biology PhD student)*

<u>Stage 3, *Decision:* Graduate students with positive attitudes towards EBT plan to implement EBT</u>

Graduate students who progressed through the *Decision* stage towards EBT adoption described specific EBT strategies that they plan to utilize if they were to design their own undergraduate biology class:

> *"I've at least heard about (EBT strategies) and I think what I really want to do now is actually implement them." (Female, 5th year Genetics PhD student)*

Because all graduate students who had a positive attitude towards EBT strategies had decided to implement EBT strategies (75% of total), no students dropped out of the model at this stage.

Stage 4, *Implementation:* Most graduate students have not implemented EBT

Graduate students who reached the *Implementation* stage described specific experiences where they had chosen to implement one or more EBT strategies as an instructor. Of the 75% of graduate students who had decided to implement EBT strategies, half actually found opportunities to do so, while the other half had not yet implemented EBT, thereby dropping out of the model at this stage (Figure 3-2). For example:

> *"I've unfortunately only after being a teaching assistant received instruction in evidence-based active learning instruction. Just being aware of that, and of some of the instructors who use such methods has really changed my opinion about how a classroom should be run." (Female, 4th year Immunology PhD student)*

Because graduate students have variable access to teaching assistantships, and sometimes little control of the curriculum, it is inherent that some graduate students do not have the opportunity to progress through the *Implementation* stage. Presumably for this reason, many of the participants who did not implement EBT seemed to have similar attitudes and perceptions as those who had actually implemented EBT. For example, both groups identified the potential benefits of EBT for undergraduate students, and they were *aware of the changing landscape of academia* (Table 3-2) that increasingly values effective undergraduate teaching.

Stage 5, *Confirmation*: Few graduate students complete the process of EBT adoption

Not all graduate students who have implemented EBT have had opportunities and/or adequate guidance to reflect on their EBT experience to the extent where they can confidently confirm that they are using strategies they would like to adopt into their permanent teaching repertoire. Despite this potentially unequal access to the *Confirmation* stage, we identified that 16% of our participants had reached this stage (Figure 3-2). The reflections of those who reached this stage positively affirmed their use of EBT strategies:

> *"Personally, my most successful student-centered learning strategies usually revolve around class discussion, usually in sort of a think-pair-share, jigsaw sort of format and, then, taking that back out into a broader overall class discussion with me and with the students more or less leading it... I think that it helps them develop, cognitively, beyond the early stages for their earlier years and up, their undergraduate experience. I would say that's probably my favorite tool, actually, Socratic method." (Male, 6th year Ecology PhD student)*

In addition to the reflective statements that defined the participants who were placed in the *Confirmation* stage, participants at this stage were highly metacognitive of their own role in the academic attitude-shift towards teaching (*part of the changing landscape of academia,* Table 3-2).

We informally observed some trends in our collected data among groups of participants at different stages in the DOI model. Participants in all stages of the DOI model described *limited instructional professional development opportunities* (lack of TA training, opportunities to teach or ability to increase their autonomy in the classroom) (Table 3-1). However, four of the twelve students who had *not* implemented EBT had the perception that EBT was not possible in large classes, while only one of the participants who actually implemented EBT expressed this perception. None of the participants who dropped out of the DOI model in the early stages (*Knowledge* and *Persuasion*) had sought out non-mandatory instructional training or teaching experiences (*seeks out teaching opportunities*, Table 3-2). In contrast, participants who reached the *Decision*, *Implementation* and *Confirmation* stages often did seek out non-mandatory teaching or training experiences. In a similar pattern, an increasingly higher proportion of participants in the *Decision*, *Implementation*, and *Confirmation* stages of the DOI model were aware of their role as *part of the changing landscape of academia* (Table 3-2). This suggests that whether or not graduate students use EBT may not be entirely controlled by their TA assignments and the circumstances of their programs, but also by the drive of the individual student to build those experiences for themselves.

TA experience, time in program, and career goals do not appear to be important factors in adoption of EBT strategies

We sought to identify if there were trends in experiences among participants who stopped or continued progressing towards EBT adoption at particular stages in the DOI model. Those who had progressed further towards adopting EBT tended to have been in their programs for longer, and had more TA experience (Table 3-3), but low sample sizes and high standard deviations to these numbers suggest that these are supporting rather than defining factors of EBT adoption. There was no indication that participation in a mandatory TA training had a positive impact on adoption of EBT—in fact, very few of the participants who progressed to the final stages of the model had taken a mandatory TA training course (Table 3-3). We also examined whether experience with biology education research (either as the primary focus of their PhD or supplemental to their primary research focus), correlated with progression towards EBT adoption. While all seven participants with biology education research experience had decided to implement EBT strategies, only one reached the *Confirmation* stage, indicating that participation in biology education research was not necessarily a factor facilitating progression through the DOI model.

There was no indication that having an interest in EBT corresponded to specific career goals, although participants who indicated that they would seek teaching-only academic positions all knew about EBT, and had at least decided to use EBT strategies in the future (Figure 3-3). Graduate students who reached the *Implementation* and *Confirmation* stages were not strictly focused on a career in teaching—several were interested in primarily research positions or in leaving academia. Only one participant who indicated that they were interested in a position that balanced both research and teaching responsibilities did not have knowledge of EBT strategies (Figure 3-3).

Discussion

In this research, we used a well-established theory to describe the adoption of an innovation (evidence-based teaching) by a novel study group (graduate students). The DOI model is a useful tool to understand where graduate students may be in the process of adopting EBT, which allows us to identify where graduate students may encounter barriers to EBT adoption. To our knowledge, this is the first study to broadly investigate graduate student perceptions of EBT at institutions across the United States, providing insight to the graduate-student level variables that likely impact TA implementation of EBT into current undergraduate classrooms.

Just under half of our graduate students reported participating in a mandatory "boot camp" TA training, a figure comparable to results of a national survey reporting on the types of professional development offered to graduates students. In the survey, 45% of participating institutions reported availability of a short pre-semester professional development training at the institutional level, and 51% at the departmental level (Schussler et al., 2015). However, in the same survey only 23% of respondents reported that instructional techniques were not addressed in their professional development programs, which contrasts with the 44% of our participants who reported that no instructional techniques were taught in their mandatory professional development training. Our finding that graduate students themselves are aware of the dearth of opportunities and support offered to develop their instructional skills is in line with other reports on graduate student perceptions (Austin, 2002; Schussler et al., 2015): when asked what graduate students would change about their professional development training, 39% requested additional pedagogical training, and 10% desired faculty acknowledgement of the value of professional development training (Schussler et al., 2015).

None of our participants described receiving substantial training in instructional strategies via a boot-camp style training (Figure 3-1B), and there did not seem to be a correlation between participation in boot-camp training and adoption of EBT (Table 3-3). This may not be surprising given recent data describing the inadequacy of "boot camp" training in providing significant long-term benefits for graduate students (Feldon et al., 2017). Additionally, a review of several studies assessing training interventions found that one-time workshops do not seem to be effective; and successful strategies lasted at least 4 weeks – and often longer (Henderson et al., 2011). However, training courses by themselves do not appear to be drivers of EBT adoption among our participants: several who reported participating in such training courses had made little progress towards adopting EBT, and none of the graduate students in our sample who adopted EBT, as described by the DOI model, had participated in a full mandatory TA training course at their institutions. Even term-long TA training courses may be insufficient in duration to incite long-term change—a recent study on a term-long intervention designed to promote TA adoption of EBT strategies did not result in consistent use of EBT by participants (Becker et al., 2017), and a survey of 1,500 graduate students found that engagement in teaching development activities for less than 30 hours did not significantly impact participant's long-term self-efficacy in teaching (Connolly et al., 2018). To better support graduate students in gaining fluency with EBT strategies, departments will want to consider the research literature on change strategies that result in anticipated outcomes (Henderson et al., 2011).

Previous recommendations for teaching development emphasize the importance of intensive and ongoing training that encourages TAs to reflect on their teaching (Schussler et al., 2008). Gardner and Jones echo this and additionally stress that formalized professional development training reinforces the perception that the institution values teaching - contrary to the climate of *lip service to teaching* that 28% of our sample indicated perceiving at their institutions. Building an institutional culture that supports and values teaching is more likely to motivate graduate students and faculty to prioritize their instructional roles (Dennin et al., 2017; Gardner & Jones, 2011). Further, we found that the graduate students who felt as though they were *part of the changing landscape of academia* (Table 3-2), and thus engaged in supporting and promoting EBT, were also the students who were progressing furthest in the DOI model. We recommend that institutions capitalize on these potential change-makers by engaging graduate students in institutional efforts to build a supportive climate around EBT. It seems likely that recruiting graduate students to participate or help lead activities such as workshops in using EBT strategies could help the students involved, their peers, and perhaps even current faculty to further adopt EBT.

In light of national efforts to improve undergraduate life sciences classrooms, it is encouraging that graduate students express interest in investing in instructional training, and appear to be largely aware of and interested in using EBT. Perhaps surprisingly, we did not detect that a graduate student's advisor played a significant role in their interest or investment into EBT in either a positive or negative direction. Since graduate students represent the pool of future faculty, their apparent willingness to use EBT suggests that future faculty may be open to embracing EBT strategies, perhaps in ways their mentors have not. Despite this, the majority of our participants had not actually implemented EBT strategies, and therefore were unable to complete the process of adoption as described by the DOI model. There are many possible explanations for the relatively low reported implementation despite high interest in EBT. Some participants may not be receiving training in these skills (as reported), while others described lacking opportunities and/or enough autonomy to enable them to incorporate EBT into their classrooms. These deficits could possibly be addressed by engaging graduate students in the process of building supportive institutional cultures towards EBT, as described above. A deeper understanding of conditions that promote or prevent graduate student adoption of EBT will require research on the relevant contextual variables as well as impacts of professional development programs (Reeves et al., 2016).

Graduate students who seek out EBT experiences are progressing further through the process of EBT adoption than those who only partake in mandatory teaching requirements. The ramifications of this could be that graduate students who are unaware of (or are not interested in) the shift towards EBT may be missing important opportunities in their professional development, which could make them less competitive applicants if they aspire towards academic careers. Graduate students who are interested in teaching positions or even research positions where they will inevitably have teaching responsibilities may be at a disadvantage if they do not have adequate support, training, and opportunities to develop EBT skills (Austin, 2002; Gardner & Jones, 2011; Reeves et al., 2016).

The graduate students in our sample who are gaining experiences that prepare them for a career in teaching were more likely to seek out such opportunities on their own, and are largely self-aware of their role in the shift in academia that values effective undergraduate biology education. It seems possible that the graduate students who are adopting EBT strategies are also the students driving change at their institutions and encouraging a culture that values evidence-based teaching. Graduate students rely on and value support from their peers (Austin, 2002), and more research on how these students may be acting as agents of change among their peers could uncover paths to supporting and leveraging these change makers. In order to more fully understand a graduate student's likelihood of not just adopting and implementing EBT, but also of being a leader in effecting systemic change, we suggest that further interview studies and national longitudinal surveys be conducted. These studies should focus on triangulating the relationship between a participant's experiences in their graduate programs, their attitudes towards teaching, and their plans to implement EBT themselves should they have the opportunity in their future. Such studies could be informed by our data indicating that, at least in this sample, graduate students value contemporary evidence-based teaching strategies, even if those surrounding them are not yet on board.

Limitations

While our study is limited by a relatively small sample size, our participants appear representative of nationwide biology graduate students in distributions of gender, race and ethnicity, and institution type. Because participants volunteered for interviews after completing a survey about their experiences with EBT strategies, our participant sample is subject to bias in favor of those interested in supporting research and promotion of EBT, and may not reflect the general population of life science graduate students. While the majority of our participants did have positive attitudes towards EBT strategies, our sample also included several participants who were largely unaware and uninterested in EBT, indicating that our sampling did not impede our ability to reach participants with diverse experiences and perceptions of EBT.

Additionally, there are many factors that could impact the rate of adoption of EBT that we were unable to address through our study. Roger's original DOI model highlights prior conditions as factors that impact the rate of adoption of an innovation (Rogers, 2003). For graduate students, these prior conditions could include their level of satisfaction with instructor-centered teaching strategies, their training in the use of evidence-based teaching strategies, their perception of the need to introduce diverse teaching strategies that can positively impact minority students, and the acceptance and use of evidence-based teaching within their program at their university. While some of these factors were addressed in the interviews, we do not attempt to robustly characterize how these complex experiences and beliefs impact our participants' rate of progression through the model.

Conclusions

Given the increasing prevalence of EBT in undergraduate biology classrooms, we are encouraged that the majority of graduate students in our sample value and show interest in evidence-based training, and it seems promising that at least some future life sciences faculty indeed plan to implement EBT strategies in their classroom. However, it is clear that these students are not generally satisfied with the support they receive from their programs in developing teaching skills. Further, it does not seem equitable that graduate students must seek-out training and experiences beyond what is required of them in order to gain pertinent professional development. It follows that students who are not taking these extra steps will potentially be underprepared as candidates for job opportunities that involve teaching. To address this disparity, we must continue learning from education research and graduate students themselves, leveraging their perspectives and utilizing best practices in training to establish effective support such that future faculty can confidently and efficaciously teach in higher education.

Figures and Tables

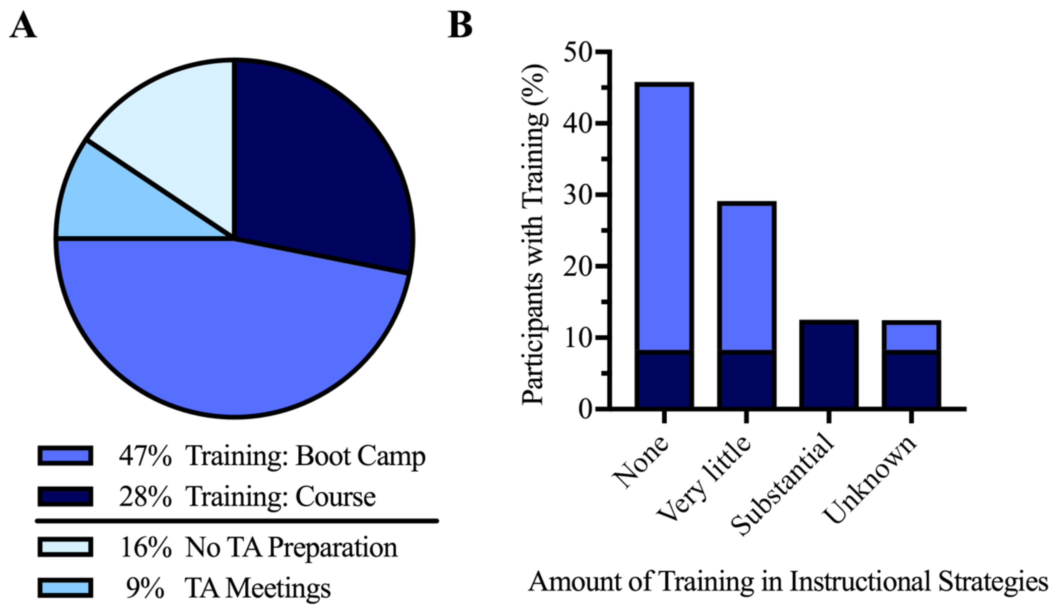

Figure 3-1. *Teacher training experience of study participants*

Most participants had some type of formal teaching training, although few of those with formal training had been trained in instructional strategies. (A) Types of teaching training that graduate students report receiving to date in their training program. (B) Reported amount of training in instructional strategies for those who participated in mandatory formal training courses or boot camp.

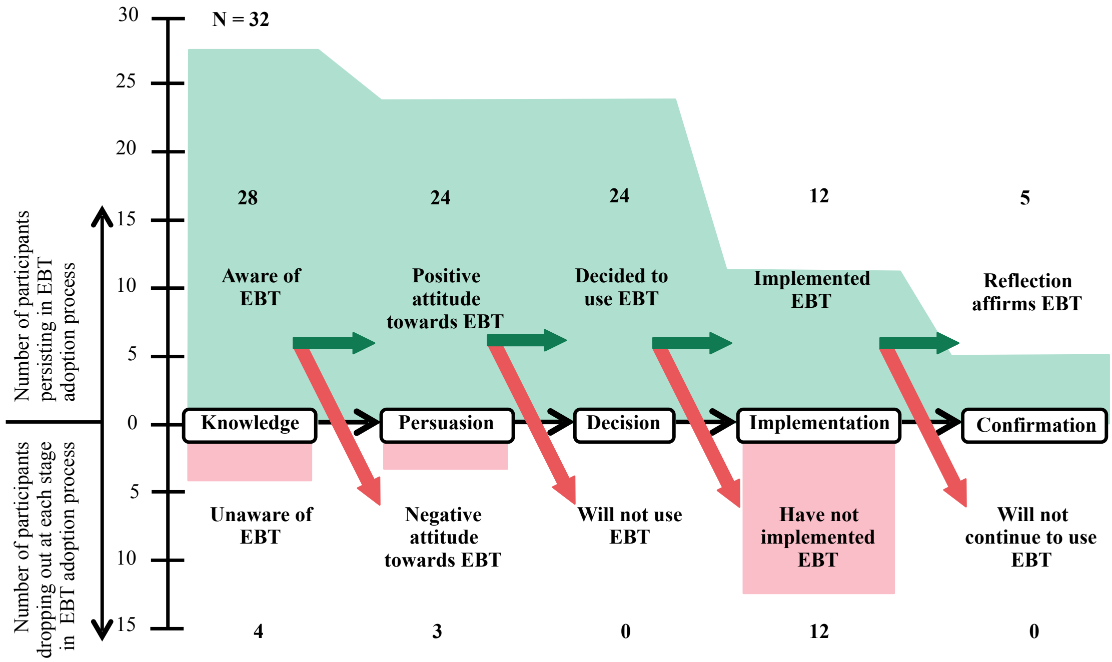

Figure 3-2. *Path of graduate students through the Diffusion of Innovations model towards adoption of EBT.*

The number of participants who demonstrated progression to each stage in the model are depicted above the x-axis (in green), while the number of participants who drop out at each stage in the model are depicted below the x-axis (in red). Some participants neither "drop out" or progress to the subsequent stage in the model—for example, while five of the twelve participants who had used EBT strategies progressed to the Confirmation stage, the remaining seven simply did not demonstrate significant reflection to either positively or negatively confirm their use of EBT strategies.

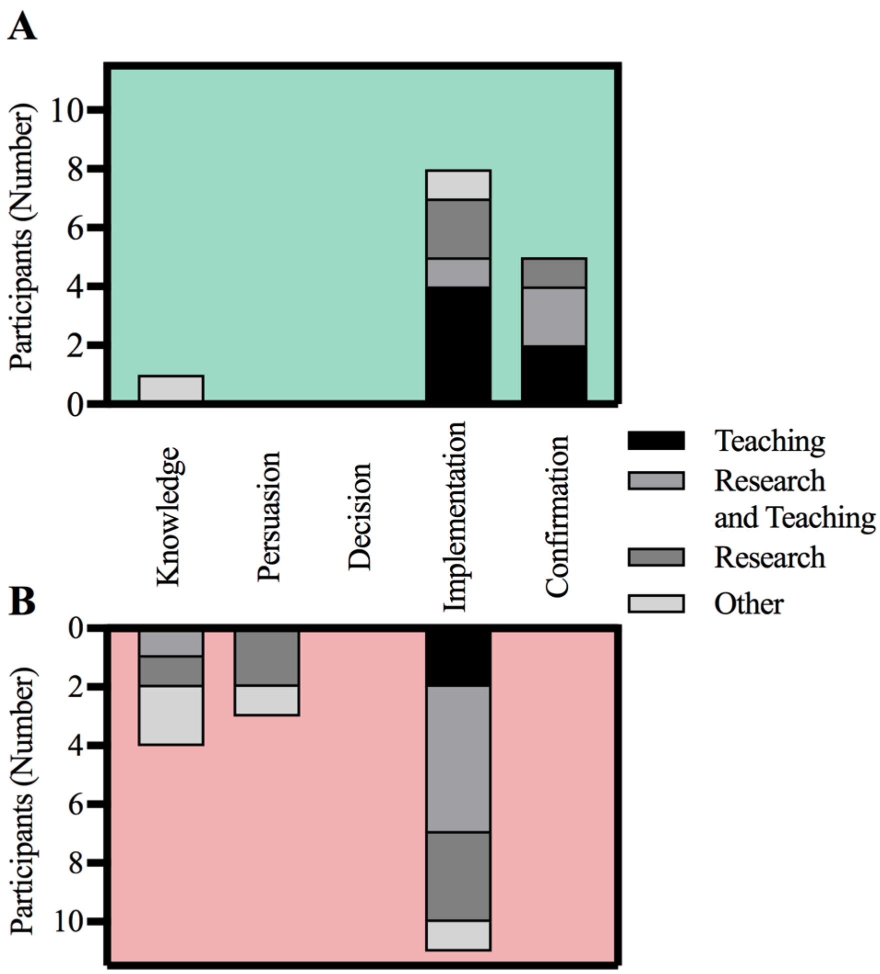

Figure 3-3. *Participants at different stages in the DOI model had varied career goals.*

All participants who were primarily interested in teaching reached the Implementation stage. (A) The career goals of participants who are in the process of progressing through the model are represented in the top graph (green). (B) Career goals of participants who have dropped out and stopped progressing through the DOI model are in the lower graph (red).

Table 3-1. *Participant perceptions regarding lack of support towards teaching from their graduate training programs.*

Theme	Theme/subtheme % of Participants (n=32)	Description	Representative Quotes
Limited Instructional Professional Development	Limited instructional training 44%	Describes lack of instructional training opportunities, or lack of incentive to participate	*"Because in most faculty positions, you do have to do some teaching, so I would encourage my department to maybe offer mandatory teaching workshops, because they're (currently) not mandatory. If you have a lot of lab work, or classes, or things that you have to do, then you never prioritize those - not mandatory workshops."* *Male, 5th year Ecology PhD student*
	Limited opportunities to teach 34%	Describes restrictions or expectations from departments, advisors, or peers that discourage or prevent graduate students from teaching	*"It would be nice if there was more interest in supporting people in being lab TAs... I really wanted to do more teaching and basically everybody told me to stop doing that… It would be nice if there was a little more support for people who wanted to teach more."* *Female, 4th year Evolutionary Biology PhD student*
	Limited opportunities to expand teaching role 34%	Expresses desire for more autonomy or responsibility in the classroom	*"(I would like a change from) being told 'This is a professor's course and here's the material, go teach it'… If I could have taken more of an active step to maybe be an instructor of record or designing my own course, or cooperatively designing a section of a course. Then carrying that out. I think that would be the most valuable thing for me right now."* *Male, 5th year Ecology PhD student*
Institutional lip service towards teaching 28%		Describe situations where they perceive their institution or department do not value or invest in instructional training or teaching, even though they may state otherwise	*"Not to be too negative about it, but I think there's a lot of language about valuing teaching and valuing science outreach and communication and having good TAs in our department, but there's also a lot of pressure to make TAing as time-efficient as possible and to make it more about us instead of our students."* *Male, 5th year Ecology PhD student*

Table 3-2. *Participant perceptions related to evidence-based teaching*

Theme % of Participants (n=32)	Description	Example Quotes
Values evidence-based teaching strategies 84%	Expresses value for EBT by indicating that active learning techniques made sense with their personal philosophy of learning, or use their personal experiences as a student or teacher to describe the practical value of EBT strategies	*"Your undergrad degree should be focused on you learning how to learn… you can't just passively receive this information."* *Female, 3rd year Biology Education PhD student* *"Different topics come up reflecting backgrounds of each student, what they have learned or what they have experienced, and I think that gives the opportunity for us to kind of dig the topic a little bit deeper."* *Female, 4th year Molecular/Cellular Biology PhD student*
Seeks out teaching opportunities 59%	Describes going beyond mandatory requirements to gain experiences in instructional training or extra teaching	*"Because I went out of my way, I got to learn about active learning and technology in the classroom and all that, but at least in my experience, it's not something you learn unless you actively try and go learn it."* *Male, 5th year Ecology PhD student* *"I think people who love teaching and are excited about teaching don't want to feel like they're doing a mediocre job. We have to take it upon ourselves to seek out training. Those resources are totally there. It has to be driven by graduate students."* *Male, 5th year Ecology PhD student*
Aware of changing landscape of academia in teaching 78%	Displays a sense of awareness for the shifting attitudes and expectations towards teaching in academia	*"I know there has been a push toward that sort of active learning, because it's supposed to get students a little bit more engaged than they would otherwise be just sitting in a lecture room, listening to the professor."* *Male, 3rd year Ecology PhD student* *"I think you're going to have to have professors who want to be there and are thinking about how to structure a class instead of finding someone who's really good at their field and being like 'Well you know a lot about this, tell people about it.'"* *Female, 6th year Molecular/Cellular Biology PhD student*
Part of the changing landscape of academia 47%	Use language or describe themselves in a way that conveys self-awareness of their role in changing the landscape of academia as it relates to teaching	*"I'm trying to get away from the traditional lecture format. Instead of spewing information at the students, really taking students' needs into account, thinking about pedagogy and active learning... My undergrad was more of just show up, get lectured at for fifty minutes, and then take the test."* *Male, 5th year Ecology PhD student* *"We started assessing our students more and kind of test them in what they have learned and we've realized that it doesn't correlate with what we want them to learn. There's this big disconnect in what we're doing and what they're actually getting out of it."* *Female, 3rd year Evolutionary Biology Master's student*

Table 3-3. *Training experiences of participants at different stages in the DOI model*

Characteristics	Stages of the Diffusion of Innovations Model				
	Stopped at Knowledge n=5	Stopped at Persuasion n=3	Have not Implemented n=12	Have Implemented n=7	Positively Confirmed n= 5
Average Year in Program	3 (±1 SD)	3.7 (± 1.5 SD)	4.4 (± 1.4 SD)	4.9 (± 0.9 SD)	4.7 (± 1.5 SD)
Average # of Terms as TA	2 (±1.9 SD)	2.7 (± 1.5 SD)	3.2 (± 2.4 SD)	7.4 (± 5.1 SD)	7.2 (± 2.4 SD)
# Participated in mandatory TA training course	3	2	3	1	0
# Participated in mandatory boot-camp training	0	1	7	4	3
# Participated in education research	0	0	4	2	1

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Chapter 4

Enthusiastic but Inconsistent: Exploring Graduate Students' Varied Perceptions of their Role as an Instructor in the CURE Classroom

Under review:

Goodwin, E.C., Cary, R.J., Shortlidge, E.E. (2021) Enthusiastic but Inconsistent: Exploring Graduate Students' Varied Perceptions of their Role as an Instructor in the CURE Classroom. Under review at *CBE—Life Sciences Education.*

Abstract

Despite growing evidence of positive student outcomes from participating in course-based undergraduate research experiences (CURE), little consideration has been given to the impacts of graduate teaching assistants (GTAs) as CURE instructors. GTAs may be novice researchers and/or teachers, and likely vary in their interest in teaching a CURE. Guided by expectancy-value theory, we explored how GTAs' self-efficacy and values, with regard to teaching a CURE, impact motivation and perceptions of their roles as CURE instructors. Using a multiple case-study design, we interviewed nine GTAs who taught a network CURE at one research institution. Although most GTAs held a relatively high value for teaching a CURE for a range of reasons, some GTAs additionally perceived high costs associated with teaching the CURE. Through the interview data we established three profiles to describe GTA perceptions of their role as CURE instructors: "Student Supporters," "Research Mentors," and "Content Deliverers." Those implementing GTA-led CUREs should consider that GTAs likely have different perceptions of their role in the classroom, as well as associated costs of teaching a CURE. The variability in GTA

perceptions of CUREs implies that undergraduate students of different GTAs are unlikely to experience the CURE equivalently.

Introduction

Evidence supporting positive impacts of student participation in course-based undergraduate research experiences (CUREs) has catalyzed efforts by universities to adopt CUREs in many introductory biology laboratory classes—a timepoint when research experiences may make the greatest impact in student interest in STEM (National Academies of Sciences, Engineering, & Medicine, 2015). In CUREs, undergraduates typically collaborate on research projects within the structure of a lab course, and through that research experience, they have the opportunity to make novel and relevant contributions to the scientific community (Auchincloss et al., 2014; Brownell & Kloser, 2015). Research on CUREs report positive student outcomes including increases in self-efficacy in research skills, interest in pursuing scientific careers, and improved retention in STEM degrees (Brownell et al., 2012; Harrison et al., 2011; Rodenbusch et al., 2016). While there is evidence of student benefits from CURE participation across course contexts, the literature rarely explicitly reflects on who is teaching the CURE. At most research institutions, graduate teaching assistants (GTAs), rather than faculty, teach traditional introductory biology labs (Sundberg et al., 2005). As universities expand implementation of CUREs, many will inevitably employ GTAs as instructors, necessitating a consideration of the potential impacts of GTA-taught CUREs—for both undergraduate students and the GTAs themselves.

Faculty instructors of CUREs have reported that the CURE environment can be very different from that of other types of courses—in both positive and negative ways. For example, faculty instructors who teach CUREs reported personal benefits such as increased enjoyment in the classroom and opportunities for furthering research productivity (Shortlidge et al., 2017). However, faculty instructors also reported experiencing hurdles including increased time investment in course implementation and planning, student resistance to CURE instruction, the unpredictability of scientific research, and the challenges of being a mentor rather than solely an instructor (Shortlidge et al., 2016). These hurdles warrant consideration—a successful CURE instructor does more than simply teach a traditional or inquiry lab class, where they might lead students in a set curriculum or guide students through experiments that have little potential for novel or relevant discovery (Brownell & Kloser, 2015; Buck et al., 2008; Domin, 1999). Rather, CURE instructors are expected to lead the class, help students troubleshoot unexpected research outcomes, serve as research mentors, and support their students in building competency and independence as researchers, all with the idea that students will collect novel data that is relevant to the scientific community. If faculty CURE instructors find this multifaceted role challenging (Shortlidge et al., 2016), it will likely also be challenging for GTAs, who are often less experienced both as researchers and as teachers.

Although it is certainly not always the case, faculty instructors may have autonomy in their decision to teach a CURE, while graduate students are likely to be placed in a teaching assignment to meet a programmatic requirement or out of necessity to receive tuition remission and/or a stipend. Multiple studies have reported that graduate students sometimes feel they lack ownership and creative license in their teaching, because unlike faculty instructors-of-record, they often have little control over the curricula they are expected to teach (Goodwin et al., 2018; Luft et al., 2004; Park, 2002). Despite this tension, biology graduate students largely have positive attitudes towards evidence-based teaching (Goodwin et al., 2018; Lane et al., 2019), and believe teaching to be synergistic with their research activities (Reid & Gardner, 2020). Although a minority of graduate students in each of these studies had clear negative attitudes towards teaching or perceived it to detract from their research productivity, evidence suggests that time spent teaching does not, in fact, reduce progress in research activities (Feldon et al., 2011; Shortlidge & Eddy, 2018). While many biology GTAs may have positive attitudes towards teaching, it is important to remember that the GTAs who do not feel enthusiastic or motivated to teach are still being placed in teaching assignments. We hypothesize that across the board, GTAs will vary in their interest and motivation to teach a CURE, which could impact their students' experiences. Biology educators have determined that CURE instructors should scaffold five distinct components within a CURE: use of scientific practices, collaboration, iteration, discovery, and broader relevance (Auchincloss et al., 2014). Specifically, GTAs who value teaching, and who buy in to the philosophy and intentions of a CURE's potential to benefit students, will be more likely to support their students' experiences with these essential CURE elements, and to embrace their role as research mentors.

To date, few studies have explored the experiences and impacts of employing GTAs to teach CUREs. Esparza et al. (2020) report that the CURE structure prompts different teaching behaviors for GTAs: GTAs of CUREs at one institution spent more time both lecturing to their students and engaging in interactive behaviors, like posing questions or talking to students individually, than GTAs of non-CURE laboratory courses. An exploratory study of the perceptions of eleven GTAs at a different institution found that GTAs appreciated the opportunity to gain experience serving as a research mentor in a CURE, but also were challenged by their perceived lack of expertise and preparedness to serve as a research mentor to CURE students (Heim & Holt, 2019). We do not know how a perceived lack of expertise or modified teaching methods, as necessitated by the structure of a CURE, will impact a GTA's understanding of and motivation for their role as a CURE research mentor.

Although we know little about the experiences of GTAs who mentor undergraduates in a CURE, studies have focused on graduate students who mentor undergraduates in apprentice-style research experiences. Graduate students are largely motivated to mentor undergraduate researchers because of perceived extrinsic benefits, such as the expectation that mentoring undergraduate researchers will increase their own research productivity (Dolan & Johnson, 2009; Hayward et al., 2017; Limeri et al., 2019). Early career mentors in particular, such as graduate students, may be more likely than experienced faculty to be motivated by external factors when choosing to invest time in mentoring (Hayward et al., 2017). Further, many graduate student mentors have intrinsic value for mentoring undergraduate researchers, describing more benefits than costs (Dolan & Johnson, 2009; Limeri et al., 2019). We expect that some of these perceived benefits and costs may shift when a graduate student takes on a mentorship role in a CURE: for example, because their mentees are not contributing to work that directly advances the graduate student's dissertation research, there may be a lower expectation for extrinsic benefits.

We first explored GTAs' perceptions of their role in the CURE classroom through an interview study (n=22; unpublished data, Goodwin & Shortlidge). We interviewed GTAs teaching CUREs in a multitude of course contexts from universities nationwide. However, it was immediately apparent that external variables, including the varying level of responsibility and support a GTA may have in teaching the CURE, and the wide diversity of structure and complexity of different CUREs, obscured our ability to isolate and compare the perspectives that individuals might hold with regard to the CURE context. We learned from these pilot data, and subsequently revised our approach: Here we used a multiple case study design to explore the experiences of individual GTAs teaching a CURE during a single term at one university. The case study approach allowed us to gain a deep understanding of the context in which GTAs were operating, and therefore to better interpret how and why individual GTAs differ in experiences, perceptions and attitudes with regard to teaching the CURE (Yin, 2017).

Theoretical Frameworks

In this work, we consider the motivation that STEM graduate students may feel towards the task of teaching a CURE. In most cases, graduate students come to graduate school with the expectation that they will conduct research, and conferral of a degree is contingent upon production of a body of research. Many GTAs may therefore be motivated to teach at least in part because they are driven by extrinsic factors (e.g. the external reward of getting a stipend, or punishment of not being able to afford graduate school without the tuition remission). Self-determination theory (SDT) proposes that these external motivators are less powerful than more autonomous drivers, such as intrinsic motivation (i.e. interest or enjoyment of an activity) and other internalized motivators (i.e. valuing an activity or seeing it as part of one's identity) (Ryan & Deci, 2000, 2020). Indeed, many studies on student motivation, including a large metanalysis on the topic, have found these more autonomous motivators are associated with improved affective and academic outcomes, which could be due to greater motivation to invest in the activity (Howard et al., 2021; Ryan & Deci, 2020). Therefore, when we consider motivation in the context of this work, we prioritize the internalized, autonomous forms of motivation that tend to result in increased investment in an activity. For GTAs teaching CUREs, this emerges as the motivation that a GTA might feel to invest and buy-in to the task of providing students with a research experience via teaching a CURE, rather than an extrinsic desire to simply complete a teaching requirement necessary to stay in graduate school.

Our study design and analysis is largely guided by Expectancy-Value Theory (EVT), which posits that the subjective value one holds for a task and their expectancy to succeed at the task will impact their their motivation to invest effort and strive to perform well at that task (Wigfield & Eccles, 2000). Subjective task value can be broken down into four main components: attainment value, intrinsic value, utility value, and cost (Eccles & Wigfield, 2002). As summarized in Eccles & Wigfield (2002), attainment value encompasses both the personal importance of the task, and the relevance of the task to one's identity, which is referred to as ideals-centered or identity-centered attainment value. Intrinsic value, as in SDT, is the interest and enjoyment one gains from the task. Utility is the value one has because of the relation the task has to current and future goals, but also represents the external extrinsic values one might have for a task. For the GTAs in this study, we therefore distinguish between professional development-centered utility value (e.g. improving teaching, research, and communication skills), and tangible utility (e.g. stipend, tuition remission, or enhancing one's *curriculum vitae*). The final component of the subjective task value framework as defined by Eccles and colleagues is cost, which includes both the negative emotional aspects of the task and the effort and opportunity-cost of participating in the task. In this study, we therefore distinguish between emotional costs and costs related to time spent on the CURE (opportunity cost).

EVT has previously been used to explore GTA's motivation to teach guided inquiry curriculum in chemistry labs through interviews with six GTAs (Wheeler et al., 2018). Three of the GTAs had high expectancy-beliefs in their ability to effectively facilitate an inquiry-based course, and these individuals also had prior experience as either a student or an instructor in an inquiry classroom, suggesting that prior experiences with the course structure could contribute to expectancy for success in teaching. GTAs in the study also reported high intrinsic value and low costs associated with teaching the inquiry curriculum, but did not perceive utility or attainment value (Wheeler et al., 2018). Although interest in CUREs has grown in recent years, CUREs are not a ubiquitous feature of undergraduate biology lab curriculum. We therefore expect that many biology GTAs would not have experienced a CURE as students themselves, and may therefore have lower expectancy for success in teaching CUREs. GTA subjective task value may also be affected by the structural differences between inquiry and CURE models—while in inquiry courses, students simulate the process of science, in CUREs, students actually participate in a research project with the potential for relevant and novel scientific discovery (Auchincloss et al., 2014; Cooper et al., 2019; Goodwin et al., 2021). However, because the intention of a CURE is to engage students in an authentic research experience, we expect GTAs may perceive higher utility and attainment value than GTAs in inquiry courses, as they will serve as research mentors to students in a manner that they may perceive to be more directly translatable and applicable to their own graduate research and/or future career.

Research Questions

Guided by EVT, we hypothesize that a GTA's subjective task value and expectancy for success will impact their motivation to perform well at teaching the CURE, and that this relative motivation will impact how the GTA perceives their role and responsibilities as a CURE instructor (Figure 4-1). Here we explore the perceptions, attitudes, and approaches GTAs take when tasked with teaching a CURE. Specifically, we use EVT to examine GTAs' (a) task value, (b) expectancy for success, and (c) overall motivation and "buy-in" to teaching CUREs and consider what these qualities can tell us about GTA perceptions of their roles in the CURE classroom.

Methods

Study Context

In 2019, we conducted a study examining a large-scale introductory biology CURE at a high-research activity institution in the Pacific Northwest. We used a multiple case study design, where each GTA and their students collectively represented a unique “case” within the overall CURE context (Yin, 2017). This site was well-suited for our study as CUREs have been implemented in the introductory biology curriculum for several years, and this is therefore a stable and consistent system with a relatively large population of both undergraduate students and teaching assistants. Lab curriculum at this institution follows the Howard Hughes Medical Institute SEA-PHAGES model, which is an established and widespread network CURE model in classrooms across the United States (Jordan et al., 2014). In this institution’s SEA-PHAGES CURE, students collaborate in teams of four to isolate bacteriophages from locally collected soil samples. Teams then enrich and purify their phage sample, make basic morphological characterizations, isolate genomic DNA samples and conduct restriction enzyme analyses of the genome. Students therefore experience the CURE elements outlined by Auchincloss and colleagues (2014) by: 1) *using multiple scientific laboratory techniques and practices* throughout the term; 2) *iterating* experiments that do not work, especially during the initial phage isolation, and 3) *collaborating* in small groups and with course instructors to complete their research project. Because of the enormous diversity of soil bacteriophages, the assumption is that any phages students collect are unlikely to have been previously characterized, allowing students who successfully find a phage to make a small but 4) *novel scientific discovery* which is recorded in an online public database. While student-isolated phages are collected and stored for potential future use by other scientists, not much is known about the bacterial host itself, and students do not have the opportunity to sequence their phage for genomic analyses, which reduces the 5) *broader relevance* of their research.

Throughout the semester, approximately 450 students enrolled in a single introductory biology course and were co-enrolled in 20 associated lab sections taught by nine GTAs. GTAs are either assigned or, in some cases, request to teach the CURE, and most teach their lab sections with the assistance of an undergraduate TA who had previously taken the course. GTAs were supported throughout the term by the faculty instructor and lab coordinator for the course and participated in a week-long CURE boot-camp at the beginning of each term as well as weekly GTA meetings. In the boot-camp, GTAs met with the faculty instructor and/or lab coordinator for two to three hours a day to discuss the purpose and intentions of conducting the CURE, receive some pedagogical training, and practice the scientific protocols that students use during the first half of the semester. During the weekly GTA meetings, GTAs met with the faculty instructor and coordinator to discuss what to expect in the upcoming week's lab and any issues they experienced while teaching, and to collaboratively brainstorm ideas for improving the labs.

We recruited GTAs to participate in our study with the help of the faculty instructor and the lab coordinator. By participating in the study, GTAs agreed to take three surveys throughout the term, participate in an end-of-semester interview, allow the researchers to observe and record their classes, and facilitate our student data collection efforts (i.e., recruiting students for surveys, and allowing us to conduct in-class focus groups). GTAs were offered a $75 gift card for participating in the study, and all nine GTAs agreed to participate. This study was approved by the Portland State University Institutional Review Board (no. 196388-18).

Interview Protocol

In this study, we explore the different perceptions and experiences of the 9 GTAs, largely derived from end-of-term interviews. Interviews were conducted by a researcher (ECG) who had experience teaching CUREs, including the SEA-PHAGES curriculum. At the time of the interview, the researcher had observed each GTA teaching for at least one CURE lab period and had been in contact with the GTAs regarding the study throughout the term. The researcher had therefore developed some familiarity with each GTA and the context in which they taught.

Interviews were designed to explore the different types of subjective task value each GTA might hold with regard to the CURE. To encourage GTAs to reflect on their value toward the CURE, we administered a card-sort activity during the first half of the interview. For the card-sort, we (ECG and EES) developed 36 statement cards, with 8-10 statements aligning to each of the four subjective task value categories (intrinsic, attainment, utility, and cost; Appendix C.1). For example, the statement "Teaching the CURE lab looks good on my CV" represents utility value, and "It is fulfilling to see students get engaged with their projects in the CURE lab" represents intrinsic value. Development of the card statements was informed by our previous work exploring the perceptions of CURE instructors, including a nationwide sample of GTAs (unpublished) and faculty instructors (Shortlidge et al., 2016, 2017). GTAs were asked to rank the cards from -4 ("Least like your experiences and perspectives") to +4 ("Most like your experiences and perspectives") and place their cards on an outlined grid in a forced normal distribution, as in Q methodology (Watts & Stenner, 2012; for grid template, see Appendix C.2). While the card sort activity was inspired by Q methodology, we did not conduct a Q factor analysis, but rather used the activity to promote reflection and guide discussions with the GTAs.

At the start of the interview, each GTA spent 15-20 minutes reflecting on the cards and silently organizing them on the board. For the next ten minutes of the interview, the interviewer prompted the GTA to explain their reasoning for each of the card placements, interrupting only to ask clarifying questions about the GTA's explanations. The remaining half hour of the interview followed a semi-structured format, with the interviewer asking a pre-determined set of questions and following up with the GTA when needed (Cohen & Crabtree, 2006; for full interview protocol, see Appendix C.3).

We piloted the interview protocol on five PhD students and recent PhD graduates who had experience as a GTA, and modified statements that caused confusion or were not interpreted as intended during the pilot interviews.

Data Analysis

We sequentially used provisional and holistic coding strategies to analyze interview transcripts (Saldana, 2015). An initial provisional codebook was generated by a single researcher (ECG). Like the card sort statements, this codebook was informed by our previous work with GTA and faculty CURE instructors and was specifically designed to capture GTA beliefs and perceptions related to both the CURE constructs and expectancy-value theory. Two researchers (ECG and JRC) then read through all GTA interview transcripts and generated new codes or clarified *a priori* codes within the CURE and EVT frameworks. Each code was a short descriptor that described an aspect of the CURE or EVT constructs and was accompanied by a longer definition to provide coders with guidance on how the code should be used. For example, within the EVT construct of Utility, we included the code "Teaching the CURE offers GTA career clarification", which we used when "the GTA finds career clarification for themselves, and the experience affirms or informs their desire to have teaching be (or not be) a part of their future career." We additionally developed a few codes outside of the EVT framework that we felt were valuable for interpreting the experiences of the GTAs, including codes that described the perceived role the GTA had in the classroom. Upon finalizing the codebook, both reviewers read through all interviews and independently coded each interview. The reviewers then met and discussed each code designation to consensus. Several additional iterations of coding ensued to check each code designation: one reviewer read through each code to check that coding was accurate and consistent across interviews, and both reviewers re-coded the mentor roles codes for each interview to ensure that the codes were used as intended across all GTAs. Finally, the reviewers re-read the interviews and used the applied codes to holistically evaluate each GTA's overall value of the CURE.

As a proxy for the saliency of different task values to each GTA interviewee, we calculated the proportional frequency with which GTAs brought up each subjective task value within their interview. To do this, we summed the codes related to each specific task value and divided the sum by the total number of codes related to any of the task values in each interview. We recognize that this is an imprecise measure of saliency: the frequency that a certain task value was discussed within the interview could be influenced by the structure and flow of the interview or the degree to which a GTA chose to elaborate on something within the conversation. Despite these limitations, we determined that the number of times each GTA referenced specific task values, when combined with the qualitative analyses of the discussion itself, provides useful insight into which task values they personally find most salient.

While considering the GTA interviews, we observed distinct patterns in the manner that GTAs spoke about their role in the CURE classroom. After our first round of coding, we therefore additionally inductively developed three codes to capture the various styles in which GTAs described their role and purpose in the classroom. We applied the code “Student Supporter” when a GTA implied that their role, purpose, or personal goal was to provide any kind of emotional support for their students (e.g., making their students feel comfortable, happy, or supported in the classroom). “Research Mentor” was applied when a GTA described offering guidance or support to students in a manner that would allow students to develop their autonomy and independence as researchers. Finally, we applied the code “Content Deliverer” when a GTA implied that their role in the classroom is to pass knowledge on to students. GTAs often expressed strong commitment to multiple roles within the space of their interview, which was demonstrated through the number of times the GTA discussed the role within the interview, the depth and emotion that the GTA attached to that role, and the number of different ways the GTA demonstrated their commitment to the role (i.e. Student Supporters might focus on encouraging their students to persist in their projects, trying to make class time fun for students, or trying to foster student’s curiosity with their research projects). We used these three codes to create profiles of each GTA’s teaching style: we assigned a holistic “Student Supporter” designation to GTAs who, in their interview, primarily made statements that we coded as

“Student Supporter,” and similarly assigned “Research Mentor” and “Content Deliverer” labels to GTAs who primarily discussed those teaching styles. Some GTAs discussed “Student Supporter” and “Research Mentor” ideas without clearly prioritizing one style over the other, and were therefore assigned a joint “Student Supporter/Research Mentor” designation.

Results

Participant information

Of our nine GTA study participants, three were pursuing master’s degrees and six were pursuing PhDs. While two GTAs were teaching the CURE for the first time, the rest had one to five terms of previous experience teaching the course. On average, participants were 29.6 years old (SD=5.2). Six GTAs self-identified as female, and three identified as male. Six GTAs self-identified as white, while three identified as South Asian international students. To protect the identity of our nine GTA study participants, we avoid connecting any personal participant information with our findings in this study. As the GTAs were teaching the SEA-PHAGES curriculum, we assigned GTAs sea-themed pseudonyms.

GTAs have a high expectancy for success in teaching the CURE

Within the interviews, we specifically asked each GTA what additional knowledge, experiences, or training would improve their ability to teach the CURE. In response to this question, and in other places in the interviews, nearly all GTAs expressed that they generally felt very confident in their ability to teach the CURE (Table 4-1). For example, while reflecting on the card-sort portion of the interview, Coral explained:

> *I had enough content knowledge [to teach the CURE]. Sometimes it could be challenging if it was something new to me, or if the techniques were different from what I am used to, but it was not difficult for me to catch up and learn how to do [the techniques] to teach the class. I think I had enough research skill and experience to guide the students through. Sometime I needed to talk to [the faculty instructors] because I didn't have experience in these experiments, but most of the time I was fine... And I really liked the [weekly] TA meetings. It prepared me for what I was going to do in the following week, which was really helpful in not getting stressed out. Especially for me, because I was teaching [for the first time]… I was always certain I could do it. I was prepared. –Coral*

Most GTAs indicated that the key to their confidence was experience (7 GTAs)—having taught the CURE once, they had the basic ability and familiarity with the protocols to teach it again. As demonstrated in the quote above, many also described the high amount of support they had (7 GTAs), which contributed to their self-efficacy with regard to teaching the CURE—the faculty instructors and other GTAs were always available to answer questions, they had an undergraduate assistant in the classroom who had previously taken the course and was available to help, and they had weekly TA meetings to discuss the course.

Only Shell, who was teaching the CURE for the first time, indicated that though they were generally confident in their teaching, they sometimes lacked confidence in teaching protocols they had never done before, and would have appreciated more training in the protocols (Table 4-1). Two experienced GTAs agreed that additional skills-based training would have been helpful before their first term in the CURE, but stated that such training was no longer necessary as they had learned the protocols while teaching in previous terms. Finally, Wave and Puffin, who did not claim to lack confidence in their ability to teach the CURE, both indicated their teaching would generally improve with more formal training in evidence-based teaching practices (Table 4-1).

GTAs prioritize several types of task value associated with teaching the CURE

We found that throughout the interviews, all GTAs described several different types of task value that were relevant to their experience in teaching the CURE (Table 4-2). Eight of the nine GTAs indicated that all four types of task value (Attainment, Intrinsic, Utility, and Cost) were relevant to their experience. We found that specific task values were clearly more salient to some interviewees than others, which was made clear in the interviews when a GTA frequently mentioned or extensively discussed specific codes that fell within certain task value categories (Figure 4-2).

<u>Attainment Value</u>

Overall, the task value category that GTAs brought up the most in their interviews was Attainment, or the value held for CUREs because they align with either one's ideals or identity (Table 4-2; Figure 4-2). By far, GTAs most frequently discussed Attainment value as it related to their ideals, or the belief that CUREs are valuable because they are particularly beneficial for undergraduates who participate in a CURE. GTAs specifically expressed the belief that CUREs are the "right" way to teach students (8 out of 9 GTAs), that students enjoy the CURE (8 GTAs), and that CUREs are more engaging for students (8 GTAs). GTAs also explained that CUREs are valuable to teach students resiliency (6 GTAs), autonomy and ownership (5 GTAs) and the process of science (5 GTAs). Compared to the time spent in interviews discussing ideals-driven Attainment value, GTAs focused much less on Attainment value as it related to their own identity and the personal importance they held, either for teaching the CURE or teaching in general. Seven of the GTAs indicated that teaching in general was very important to them or that they took their teaching responsibilities very seriously, and four of those GTAs additionally planned to have teaching be a major part of their future career. Just over half (5 GTAs) explained that the CURE format specifically aligned with their identity as a researcher, since they were able to teach students the process of research and/or make connections between their graduate work and the CURE.

Intrinsic Value

While on average, GTAs tended to discuss their Intrinsic value for the CURE less frequently than Attainment, Utility, or Cost, eight of the nine GTAs found their experiences to be, at least on occasion, rewarding or enjoyable (Table 4-2; Figure 4-2), as did faculty instructors of CUREs (Shortlidge et al., 2017). GTAs also described intrinsic value for the CURE in the sense that they appreciated their interactions with students (5 GTAs) and their relationships with the CURE faculty instructors (4 GTAs). Four GTAs described that they valued the autonomy they had in teaching the CURE, and felt they had control and responsibility in the CURE that they might not have in other GTA positions.

Utility Value

All nine GTAs indicated that they perceived Utility value in the CURE, particularly in the professional development skills they were able to cultivate (Table 4-2; Figure 4-2). Specifically, GTAs described that teaching the CURE improved their teaching or mentoring skills (7 GTAs), or their research or biology skills (5 GTAs). Five GTAs indicated that teaching the CURE helped develop their communication skills, and three GTAs found that their experiences with the CURE had helped inform their own career interests.

Surprisingly, only six of the GTAs discussed the tangible Utility benefits from teaching the CURE, and these six GTAs tended to discuss these tangible benefits only briefly. While many GTAs acknowledged that getting their stipend and tuition remission from teaching was, of course, important, only five of the GTAs expressed that this was one of the primary reasons why teaching the CURE was valuable to them. Five GTAs also acknowledged that teaching the CURE could provide professionally useful tangible benefits, in that it might look good on their *curricula vitae* or provide beneficial networking opportunities. Because previous interviews with faculty CURE instructors have revealed that faculty instructors may experience tangible benefits such as publications, recruitment of undergraduate research assistants, or professional recognition from their universities (Shortlidge et al., 2017), we intended to track when GTAs report the same tangible benefits. However, we found that GTAs did not discuss these potential CURE benefits at all, and sometimes specifically said they did not expect to publish or that they felt their departments specifically did not value their work as a GTA (coded as "Emotional Costs;" 2 GTAs).

<u>Cost</u>

Although eight of the nine GTAs discussed personal costs associated with teaching the CURE, GTAs varied the most in the number of times they referenced this theme, indicating that costs associated with the CURE are likely are very salient for some GTAs and not a substantial issue for others (Table 4-2; Figure 4-2). Specifically, these eight GTAs all discussed the emotional costs of the CURE: that teaching the CURE could be frustrating or exhausting because it can be difficult to get their students engaged and excited to participate in the CURE. Some GTAs also found it challenging to deal with students who were frustrated by experiences of iteration or failure in the CURE (4 GTAs). Finally, seven GTAs discussed that a major cost of teaching the CURE was time spent away from research, though GTAs did not spend much time in their interviews discussing this point.

Perceived value impacts GTAs' motivation and "buy-in" to teaching the CURE

When considering each GTA's interview as a whole, it was apparent that certain GTAs "buy-in" to the CURE pedagogy more than others, through their repeated emphasis of the value they see in the CURE experience either for their students and/or for themselves. Seven of the nine GTAs felt that CUREs were overall a very beneficial experience for introductory students (Table 4-3). When assessing value, we considered specifically the elements that the CURE structure brought to the class in question—for example, Orca believed that a research-based lab course could potentially be beneficial, but that a traditional lab course would be most beneficial for the introductory biology undergraduates in the course they were teaching. While Shell felt the CURE was very engaging for students, they too ultimately doubted the utility value for students:

> *"I don't know whether [this type of research] is something [students] can really put on their resume, so I don't know how much it really benefits them. –Shell*

While most GTAs felt that teaching the CURE was a net positive and valuable experience for GTAs as well as for their students, Urchin, Wave, and Orca all felt that overall, teaching the CURE was not necessarily advantageous for GTAs (Table 4-3). For example, while Wave thought CUREs were good for their students and recognized many professional development opportunities within a CURE, they ultimately felt that time spent teaching was a net negative for GTAs, as demonstrated below:

> *"I don't think TAing is a massive resume builder…. TA experience can help [build your resume], but it also comes at the cost of having less research experience... Probably more than one semester of TAing isn't going to help your CV that much. And I do not feel like teaching [the CURE] contributes to my research. I'd actually say that it really detracts from my research in a lot of different ways as my time is directed more towards teaching and learning how to teach than it is to getting my papers published and my research done." –Wave*

We directly asked GTAs if they would use a CURE model if they were designing their own introductory biology lab class, and most GTAs affirmed that they would use a CURE model (Table 4-3). Only Sand and Orca expressed reservations about a CURE model, primarily because they felt that an introductory biology class should prioritize reinforcing concepts taught in the lecture associated with the lab course. Notably, Sand and Orca perceived more costs and less ideals-based attainment value associated with the CURE than any other GTAs in our study (Figure 4-2), indicating that they feel that the potential benefits of implementing a CURE may not outweigh the costs.

Graduate students see themselves as "Research Mentors," "Student Supporters," and/or "Content Deliverers"

We expected that GTAs who perceive that the CURE is ultimately a valuable experience—either for students or themselves—will be more likely to embrace their role in serving as CURE mentors in the classroom. We therefore were curious about how GTAs perceived their role in the CURE classroom, and how those perceptions aligned with their buy-in to the CURE. We found that we could categorize the manner in which graduate students describe their role in the CURE classroom as either a "Research Mentor," with the goal to build their students' autonomy and independence as a researcher, a "Student Supporter," with the goal to support their students emotionally (e.g., happiness, comfort, engagement, or confidence), or a "Content Deliverer," with the goal to pass knowledge on to students (Figure 4-3). Below, we explore four profiles of GTAs with varying conceptions of their role as a CURE GTA.

<u>Balancing roles as a Student Supporter and Research Mentor: "Don't get scared if you fail."</u>

Nearly half of the GTAs (Krill, Sand, Coral, and Urchin) had balanced views of their roles as both a Student Supporter and Research Mentor in the CURE classroom (Figure 4-3). These GTAs often demonstrated their commitment to developing their students as researchers while providing emotional support by making an effort to increase morale and normalize failure and iteration in the research process, as demonstrated by Krill:

> *"The first time they don't get phage, [I tell them] 'Research is 99% troubleshooting', and I give them my example: 'I've been working [on part of my research] for six months and I ended up getting nothing, but I'm still here teaching and smiling, so you guys should not be sad.'" –Krill*

Krill, Coral, and Urchin all had high ideals-centered attainment value for the CURE, indicating that they valued the CURE because they held the strong belief that it is beneficial for their students. Their belief in the value of the CURE for undergraduates perhaps motivated their commitment to their dual roles as Research Mentors and Student Supporters, as they felt that the CURE offered an opportunity for students to develop many of the affective qualities that would make them stronger researchers and students:

> *"[The most important thing undergraduates learn in the CURE is] being independent and learning to make decisions, and to take the responsibility of those decisions… And to teach them to have self-confidence, and to not get scared if they fail or if something goes wrong… You have to have a plan B, and it can be made up." –Coral*

Krill in particular articulated a sometimes-conflicting desire to satisfy their students' frustration in the CURE while also serving as a research mentor in the classroom:

> *"Sometimes I wish I could give them the phage. Make their life easy… But then I say, 'No, that's their research, and I'll let them figure it out." –Krill*

We found it notable that, although these four GTAs struck a balance of their Research Mentor and Students Supporter roles in the classroom, Krill was the only one who specifically indicated they intended to have teaching be a prominent part of their future career. Further, Sand and Urchin both emphasized they have no intention of pursuing a career in teaching and expressed reservations about the overall value of the CURE. Urchin in particular perceived much lower professional utility in teaching the CURE and discussed the time-costs associated with teaching the CURE more than any other GTA. Sand experienced much higher emotional costs while teaching the CURE, mostly connected to a perceived lack of student interest and engagement:

> *"Especially when I first started teaching this course, I got so emotionally invested in my students' performance and understanding and them caring [about the CURE], so this semester, I've taken the philosophy that you can't make someone care. You just have to be there to support the people that do care, and then encourage those that don't." –Sand*

Despite these costs and lower perceived value for the CURE, both Urchin and Sand demonstrated that they took their instructional role in the classroom seriously and were committed to acting as both a Student Supporter and a Research Mentor.

<u>Student Supporters: "Good job, keep it up."</u>

Wave and Shell expressed strong commitment to their roles as Student Supporters in the CURE classroom (Figure 4-3). Although Shell expressed a strong teaching identity and passion about teaching, they had little previous research experience and did not express much of a research identity themselves. This perhaps explains why they did not prioritize fostering a research identity in their students, but rather focused on engaging and encouraging students:

> *[One of my most meaningful responsibilities is to provide students] encouragement to do a good job, to get their work done... A lot of them get in this mindset of, "This is boring, and I don't like this." That's your attitude, it doesn't have to be boring…. [Some days there is] not necessarily a lot for me to do except watch: 'Good job. Keep it up. You're following those protocols well.'" –Shell*

Shell's dedication to engaging students perhaps explains why they experienced high emotional costs in the CURE, as they found their students' lack of enthusiasm about the CURE particularly frustrating and exhausting. However, Shell also found the CURE to provide more tangible utility than other GTAs: while other GTAs felt that their experience teaching CUREs would not matter much to future employers, Shell's limited previous research experiences meant that the CURE was consequently an important addition to their CV in terms of demonstrating their research skills and experience.

Like Shell, Wave made it clear that they were passionate about teaching. Although Wave enjoyed the CURE and believed in the importance of evidence-based teaching and a research-based curriculum, they struggled with the time commitment and felt it detracted from their graduate research. While those in the "Research Mentor" role prioritized fostering student research skills and autonomy, Wave prioritized building student engagement and curiosity towards research, especially at the introductory level:

> *"The best I can do as a teacher is just try to engage them and try to drive that curiosity that encourages them to investigate a topic further… Introductory classes [like the CURE] are where you teach them how to learn, and later classes are when you actually help them develop their critical thinking skills to apply new information." –Wave*

Research Mentors: "You [students] are the researcher."

Like the GTAs who balanced their roles as Research Mentors and Student Supporters in trying to reduce student frustration with iteration and failure by normalizing these aspects of research, Puffin and Kelp emphasized the importance of iteration and failure with their students as they prioritized building student research skills and autonomy (Figure 4-3). However, unlike the Research Mentors/Student Supporters, they emphasized these aspects of research without indicating that boosting student morale or supporting student confidence was a priority for them:

> *"[I tell them] You are the researcher. You need to be patient. Everything in the lab, it doesn't come at once. You need to repeat it." –Kelp*

Although they did not discuss efforts to support their students emotionally in the course, they both clearly were passionate about teaching and cared about their students' success. Puffin explained:

> *"My most meaningful responsibility… [is to give my students] tools that are going to help them be successful in other courses or in their future career." –Puffin*

Both Puffin and Kelp planned to have teaching be a significant portion of their career, and more than other TAs they focused on how teaching the CURE aligned with their personal and professional values with regard to teaching and research (identity-centered attainment value). Puffin in particular expressed a strong interest in improving their own ability to incorporate evidence-based teaching strategies into their classroom and recognized the professional development opportunities (utility value) with teaching the CURE.

Content Deliverer: "My responsibility is to give the best knowledge to the students."

Orca stood out from the other GTAs in that they did not embrace either the Research Mentor or Student Supporter roles, but rather focused on transmitting instructions and knowledge to their students (Figure 4-3):

> *"[I told my students,] 'Your priority is to follow me, follow instructions, do research, and write.'... But most students are just naïve. They are just starting in this field." –Orca*

As demonstrated above, Orca frequently spoke about their students with some derision, and overall expressed less value for the CURE than other GTAs (Table 4-3). Within their interview, Orca focused less than the other GTAs on the benefits undergraduates received from the CURE (ideals-centered attainment value) and had the lowest intrinsic value and value for the professional development opportunities the CURE offered GTAs. Orca was the only GTA who expressed a strong preference for traditional "cookbook" labs to CUREs, at least at the introductory biology level:

> *"Some students [in the CURE] don't understand what is going on. They start to believe that I'm not good at teaching: "[Orca's] not aware of what [they are] doing…" So maybe they have less appreciation for my effort [in a CURE]. But when it's a cookbook course, everything's prepared, and I know [what to expect] ... The cookbook is more enjoyable for me… When [the students] get the results that I expect, I'm ready to elaborate and build on what they have seen in the test-tube or the DNA extraction... [In the cookbook labs,] I'm ready for everything." –Orca*

Orca spent more time than any other GTA discussing the costs associated with the CURE, and particularly highlighted experiencing high emotional costs (Figure 4-2). This in part was a product of their frustration with the lack of engagement and appreciation they received from their students and the uncertainty involved in teaching a CURE compared to a more traditional course (as portrayed in the quote above). Orca, who had previous experience teaching as an instructor-of-record, also felt frustration with the perceived lack of control they had over the curriculum, since Orca was expected to follow the faculty instructor's vision for how the CURE should be taught, rather than teach in the way that suited them.

Discussion

We conducted this exploratory study to understand the experiences and perceptions of GTAs within a single CURE context, asking: what influences a GTA's motivation to engage in teaching the CURE, and how do they perceive their role as a CURE mentor? It is clear from our work that the experiences of GTAs are likely very different from the experiences of faculty CURE instructors. For example, GTAs in our study did not perceive a lot of tangible utility value in a CURE beyond the financial incentive and the addition of the experience to their resume. In contrast, faculty instructors of CUREs report experiencing benefits such as the possibility of publication, recruitment of undergraduate researchers into their research lab, and professional recognition from their department (Shortlidge et al., 2017). When prompted about these potential benefits during the card-sort portion of the interview, GTAs often specifically emphasized that they did not experience these outcomes—they had no expectation of publications resulting from their work in the CURE, and Urchin and Orca in particular reported feeling a specific lack of recognition and appreciation for their work as CURE instructors from their departments and/or students. The absence of these perceived tangible benefits is not surprising given that the CURE did not relate to the GTAs' own research interests and the GTAs were not involved in developing the CURE: faculty instructors who implemented network CUREs (such as SEA-PHAGES) unrelated to their own research interests were also less likely to experience tangible benefits compared to faculty who developed their own independent CURE (Shortlidge et al., 2017). These different perspectives of faculty and GTA instructors of CUREs likely translate into different approaches when teaching the CURE: previous research has found that undergraduate students perceive GTA and faculty instructors differently, in that GTAs are thought to have less expertise and confidence, but may be more laid-back and relatable than faculty instructors (Kendall & Schussler, 2012). It is therefore critical to consider the impacts of GTA-taught CUREs from the perspectives of students, and to further examine the instructional contexts in which CUREs appear to be effective as a teaching strategy for introductory biology labs.

Expectancy-value theory predicts that individuals with high value and high expectations for success at a task will experience increased motivation to engage in that task (Figure 4-1; Wigfield & Eccles, 2000). When applying this theory to the motivation a GTA might have for teaching a CURE, we first considered each GTA's expectations for success, or self-efficacy in teaching the CURE. As seen in previous studies on GTA self-efficacy in teaching, GTAs in our study were, overall, quite confident in their ability to teach a CURE (Table 4-1; DeChenne et al., 2015; Prieto & Altmaier, 1994). In discussing their expectations for success regarding teaching the CURE, many expressed the opinion that their hands-on experience in teaching the CURE curricula once was sufficient to build their strong self-efficacy in teaching the CURE. GTAs also emphasized that they felt confident in their abilities to teach the CURE because they had extensive training and support from faculty members, undergraduate assistants who had taken the course, and other experienced GTAs. These findings mirror previous studies suggesting that GTA self-efficacy is correlated with previous teaching experience (Prieto & Altmaier, 1994) and an environment that supports their teaching (DeChenne et al., 2015). Faculty instructors of CUREs echo that a supportive institutional environment is critical to successfully teaching CUREs (Shortlidge et al., 2016). We therefore expect that GTAs of CUREs who have less experience or support may therefore not experience the same high degree of self-efficacy as the GTAs in our study. While we expect this strong self-efficacy among the study participants to support their motivation to teach the CURE, recent work has found that GTA assessments of their own self-efficacy do not significantly correlate with student evaluations of their GTAs (Smith & Delgado, 2021), indicating that students have differing perceptions of their GTA's efficacy in the classroom.

Contrary to previous work using EVT to examine GTA motivation to teach chemistry inquiry courses, which found that GTAs only described intrinsic value regarding their inquiry teaching (Wheeler et al., 2018), we found that GTAs simultaneously endorsed a wide variety of task-value related beliefs, including multiple dimensions of attainment, intrinsic, utility, and cost value (Figure 4-2). The differences in our findings could have been due to our methodological approach—our interview card sort activity prompted GTAs to consider these different types of value—but it also is logical that GTAs would perceive differences in the value of teaching an inquiry course compared to a CURE. For example, the ideals-driven attainment value and emotional costs reported by GTAs of the CURE were often specifically linked to the experience of engaging students in research activities and dealing with student frustration of experimental iteration and failure—which GTAs may be less likely to experience in an inquiry course.

Overall, the majority of GTAs discussed the utility, attainment, and intrinsic value of a CURE much more frequently than they discussed the costs (Figure 4-2), and holistically recognized high value in teaching using a CURE model (Table 4-3). Although we expected that GTAs might perceive less extrinsic or utility value than reported for graduate mentors in traditional research settings, we found GTA attitudes overall to be strikingly similar to reported attitudes that GTAs have towards mentorship in traditional research settings (Dolan & Johnson, 2009; Hayward et al., 2017; Limeri et al., 2019). Although GTAs in our study perceived the extrinsic/utility value of mentoring in a CURE to lack potential benefits of traditional research mentorships, such as an increase in research productivity, GTAs of CUREs likely recognize different types of utility value in teaching the CURE, such as professional development. GTAs varied the most in the frequency with which they discussed costs associated with the CURE—even GTAs who seemed to have relatively high value for the CURE, such as Krill and Sand, perceived significant costs. While some GTAs had more reservations about the CURE than others, only one GTA (Orca) firmly did not see value for students and indicated that the costs associated with the CURE outweighed the value.

We expected that GTAs who perceived high value and buy-in for the CURE would be motivated to embrace their role as CURE mentors and predicted that this motivation might impact how GTAs described their role in the classroom. We categorized the roles that GTAs in our study described as either a “Student Supporter,” “Research

Mentor," or "Content Deliverer," and pose that ideally, a CURE GTA should strike a balance between the "Student Supporter" and "Research Mentor" roles, in order to support their students emotionally while developing their autonomy as student researchers (Figure 4-3). As expected, we found that the single GTA who expressed decisively low value for the CURE did not appear to express commitment to either the "Student Supporter" or "Research Mentor" roles, and rather saw themselves as a "Content Deliverer"—a role that aligns more with traditional cookbook style laboratories, rather than a CURE. However, when we consider the other eight GTAs who had less extreme negative perceptions of the CURE, we found that commitment to balancing the "Student Supporter" and "Research Mentor" roles did not correspond to experiencing particularly high value and low cost for the CURE (Figures 2; 3). Our findings corroborate those of a previous case study of eight GTAs, in suggesting that even within a single course context where GTAs are receiving identical training and institutional support, GTA perspectives of teaching can be quite variable, and individual perspectives may not correlate with GTA teaching practices (Addy & Blanchard, 2010).

Previous studies have found that GTAs can be hesitant to facilitate inquiry-style learning in their teaching, often gravitating towards traditional content-delivery style teaching even in inquiry-based courses (Gormally et al., 2016; Kurdziel et al., 2003). However, the eight GTAs who perceived at least moderate value for the CURE did not strongly endorse a "Content Deliverer" role in the classroom—we believe this is positive as it indicates that these GTAs were not embracing a role antithetical to the ideals of a CURE. At the same time, these GTAs did not unanimously commit to balancing the

“Student Supporter” and “Research Mentor” roles, despite all having received the same training and support throughout the CURE (Figure 4-3). This highlights the importance of individual GTA characteristics in proposed models of GTA professional development with regard to teaching, such as the model proposed by Reeves et al. (2016). While high perceived costs and low value for a CURE may be a warning sign that a GTA could be unprepared to balance the roles of a Student Supporter and Research Mentor in a CURE, faculty coordinating CUREs should not assume that GTA characteristics such as career aspirations and apparent enthusiasm for teaching the CURE predicts an accurate or consistent interpretation of their role as a GTA instructor in the CURE classroom.

Limitations

We used a case study research design to gain an in-depth understanding of the experiences of GTAs in a CURE. To accomplish this, we limited our data collection to a single institution and course context, similar to another study of CURE GTAs (Heim & Holt, 2019), and conducted detailed interviews with the nine GTAs involved with the course. The experiences of GTAs in CUREs are highly context-dependent, and likely vary greatly depending on a multitude of factors, such as the training offered to GTAs, in-class support, type of CURE, and the structure of the course. Further, we are unlikely to capture a full range of experiences through conversations with nine individuals. GTAs of CUREs who are offered less training or in-class support may have lower self-efficacy, and variables such as GTA training, CURE type, and institutional culture could impact a GTA’s value and understanding of their role in the CURE classroom. The experiences of GTAs in the course context of our study are unlikely to translate directly to any other context, but rather serve as an example of the possible values and role-related perceptions GTAs may have in a CURE and demonstrate the variability of GTA experiences and perceptions even within a single course context.

Within the interviews, some GTAs clearly felt stronger about certain costs and values related to teaching a CURE than others, and individuals differed in the frequency that they returned to certain ideas within the interview. We used the number of times a GTA brought up each of the EVT task values as a proxy for how salient that task value was for the GTA, but this is a far from perfect measure of true saliency: GTAs may have returned to certain ideas within the interview because the natural flow of the conversation prompted them to do so, or they could have been influenced by recent experiences that happened to come to mind during the interview. Although we found it useful to quantify the number of times a GTA discussed each EVT task value within their interview, we intend for these numbers to be used as an approximation rather than a precise measure of the saliency of each task value for GTAs.

Finally, we attempted to create a space for GTAs to be comfortable expressing their true perspectives and attitudes by coming in as external researchers unaffiliated with our participant's university, departments, or other social networks. We emphasized to GTAs that their responses would not be shared with the instructors of the course, and any information GTAs provided would be deidentified. Despite these precautions, GTAs were aware of the purpose and intentions of the research study, and this knowledge could have impacted the positions GTAs expressed during interviews.

Conclusions

This work is among the first to report on the experiences and beliefs of GTAs who teach CUREs. Those implementing GTA-led CUREs should consider that GTAs likely have different perceptions of the value and costs associated with teaching a CURE both among themselves and as compared to faculty instructors of CUREs. While GTAs may value the experience of teaching a CURE, they may also have unique perspectives of their role in the classroom. We encourage faculty instructors and coordinators of GTA-led CUREs to consider that GTAs may need increased support in developing their role as a CURE mentor.

Variable beliefs and attitudes held by GTAs of CUREs could indicate that students of different GTAs are unlikely to experience the CURE equivalently. Further research can explore how student's experiences in a CURE are influenced by their individual GTAs, and if GTAs with variable perceptions of their role in a CURE are able to provide students with the "ideal" CURE experience.

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Figures and Tables

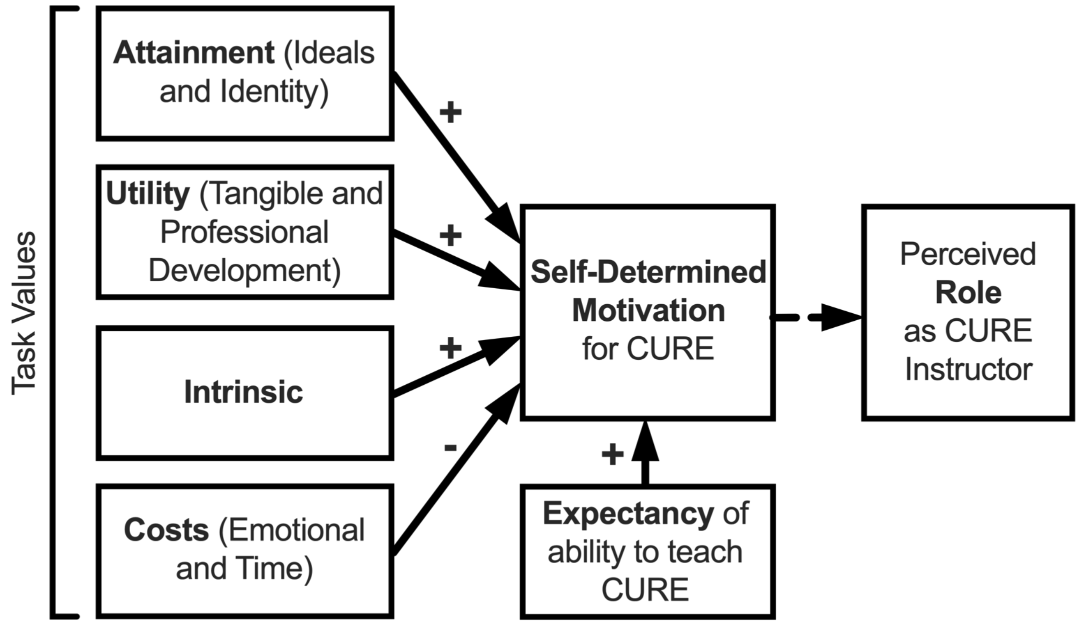

Figure 4-1. *Expectancy-value model of GTA autonomous motivation for a CURE.*

Task Values and Expectancy to succeed may affect GTA autonomous motivation to invest in teaching the CURE. GTA motivation may, in turn, impact how GTAs perceive their Mentor Role. Modified from Wigfield & Eccles, (2000).

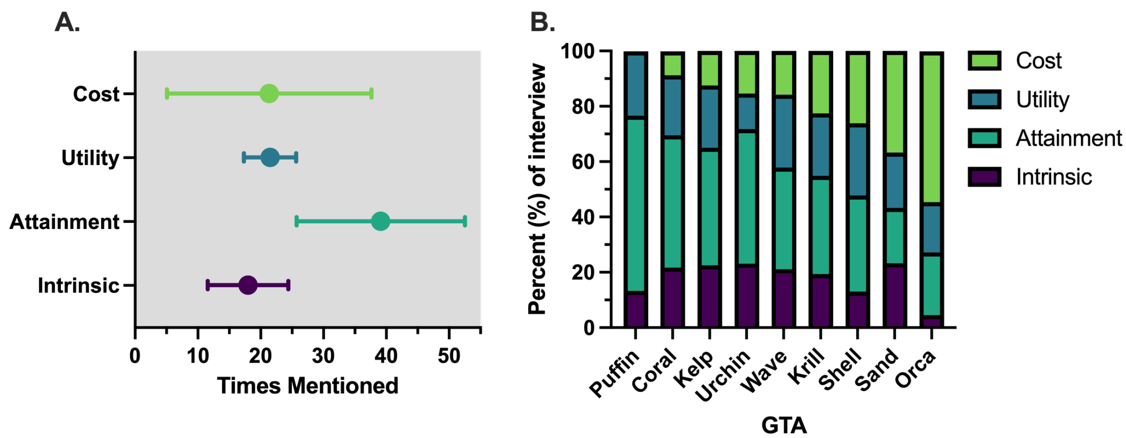

Figure 4-2. *The saliency of each EVT task value to GTAs.*

A. *On average, GTAs most frequently discussed their attainment value for the CURE, and GTAs varied the most in how frequently they discussed attainment value and costs associated with teaching the CURE. Circles represent the mean number of times (± one SD) each construct was mentioned in GTA interviews.* ***B.*** *Individual distributions of the frequency in which each GTA discussed Cost, Utility, Attainment, and Intrinsic value for the CURE as a proportion of their entire interview.*

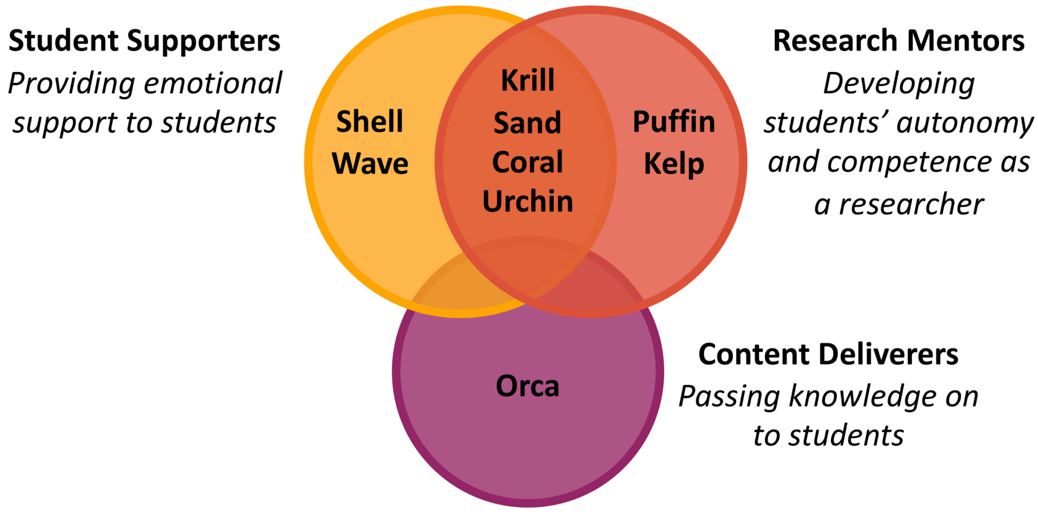

Figure 4-3. *GTA roles as a Student Supporter, Research Mentor, or Content Deliverer in the CURE classroom.*

GTAs vary in the manner in which they appear to prioritize these different perceived roles as a CURE mentor.

Table 4-1. *GTA's expectancy beliefs about their ability to teach the CURE*

GTA[a]	Krill	Sand	Coral	Urchin	Wave	Shell	Puffin	Kelp	Orca
Feels confident and capable in teaching CURE	✓	✓	✓	✓	N/A	~	✓	✓	✓
Indicates that more training would have improved teaching	✗	N/A	✗	✗	✓	✓	✓	✗	✗

[a] A ✓ indicates the GTA firmly expressed a particular sentiment, a ~ indicates the GTA expressed uncertainty in their response, and an ✗ indicates the GTA specifically stated the opposite of the sentiment (e.g. they did not feel that more training would improve their teaching). N/A indicates that the GTA did not clearly address the topic in their interview.

Table 4-2. *Task value codes with example GTA interview quotes*

Code and Definition	GTA Example Quote
Attainment (Ideals): GTA believes that CUREs are important because they are valuable for the undergraduate students.	*"[Compared to traditional labs, CUREs] give students a better introduction to what research is like. It reinforces students' ability to acknowledge what is genuine research and what should not be considered as research…. I think it really engages students. I think it's a good teaching mechanism and I think it gives them a much more realistic expectation for future careers in this field."* (Wave)
Attainment (Identity): Teaching (either the CURE or in general) is personally important to the GTA.	*"Teaching is my passion. Maybe in future I'll choose the teaching profession. [Teaching the CURE] is just part of teaching, so I'm enjoying it actually."* (Kelp)
Intrinsic: GTA finds teaching the CURE to be rewarding, stimulating, or enjoyable.	*"It was fun. It was enjoyable. I really enjoyed teaching this class and seeing the students engaging in their projects…. I could even use the examples coming from my PhD research to teach them the material, which was helpful and kind of interesting for me. And compared to other TAships that I had before, I had more responsibilities, but that was not something bad. I liked it."* (Coral)
Utility (Professional Development): GTA acknowledges benefits from teaching the CURE. Benefits include developing their communication, research, and mentoring skills, or clarifying their own career goals.	*"When you're teaching how to do research and you're learning how to do it yourself as a grad student, the more you know, the more you can tell your students. And the more you teach it, the more you're thinking about it as well. Even if you already know it, you're further gaining expertise by teaching it."* (Puffin)
Utility (Tangible): GTA acknowledges teaching the CURE is useful to them. It may pay their stipend/tuition, or it offers tangible professional benefits (looks good on a curriculum vitae, helps them get jobs, etc.)	*"Being paid in tuition is actually huge, because I wouldn't be able to even be here at school [without teaching]. I wouldn't be able to pay for [school]…. I'm going to have to keep going in a PhD, so having TA experience on my resume can be a good thing."* (Shell)
Costs (Emotional): GTA expresses teaching the CURE has costs. It may be frustrating or emotionally exhausting, often because it is difficult to engage students or to deal with students who are frustrated with iteration/failure in the course.	*"It can be difficult to get them excited when they don't get a phage. I mean the success rate is very low, and they end up writing in the reflection, 'We did everything correctly but we didn't find a phage.' Like they are trying to blame things on you [the GTA]." (Krill)*
Costs (Time): GTA expresses that time spent teaching the CURE is an inconvenience.	*"In our department, teaching isn't valued very much and it's basically just seen as a way to pay your tuition and stipend if your PI can't fund you. But you're still assessed in the same way as students who don't have to TA. I feel like it's not really taken into account like, 'Hey, I have to spend like 15 to 20 hours a week teaching,' because nobody seems to really care about that. They just care about your actual research progress."* (Urchin)

[a] Quotes have been lightly edited for grammar, clarity, and to protect the anonymity of our participants.

Table 4-3. *GTA perceptions of the value of teaching a CURE* [a]

GTA	Krill	Sand	Coral	Urchin	Wave	Shell	Puffin	Kelp	Orca
Sees value in CURE for students	✓	✓	✓	✓	✓	~	✓	✓	✗
Sees value in CURE for GTAs	✓	✓	✓	✗	✗	✓	✓	✓	✗
Would teach using CUREs in introductory biology labs in the future	✓	~	✓	✓	✓	✓	✓	✓	✗

[a] A ✓ indicates an affirmative agreement or belief from the GTA described in their interview how they or their students benefited from the CURE, a ~ indicates the GTA expressed uncertainty in their position, and an ✗ indicates the GTA stated they thought the CURE lacked value for the students/themselves.

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Chapter 5

Whose CURE is it anyway? Undergraduate students' experiences in CURE labs vary by graduate teaching assistant instructor

In prep for submission:

Goodwin, E.C., Cary, R.J., Shortlidge, E.E. (2021) Same Course, Different TA: How Student Experiences of a CURE can Vary Dramatically, Depending on Instructor. In prep for submission to *PLOS*.

Abstract

In an effort to expose all undergraduate science students to the benefits of participating in research experiences, many universities are integrating course-based undergraduate research experiences (CUREs) into their introductory biology lab curriculum. At large institutions, the bulk of introductory laboratory courses are instructed by graduate student teaching assistants (GTAs). Graduate students, who are often novice teachers and researchers, likely vary in their capacity to effectively teach undergraduates via the CURE model. To explore variation in GTA teaching and the outcomes for students, we used a case study research design at an institution where introductory biology students participate in GTA-taught CURE lab sections. We used multiple data sources, including in-class focus groups, worksheets, and surveys to explore how students perceived: 1) the learning environment their instructor created; 2) the learning objectives emphasized by GTAs throughout their course; 3) their understanding of the purpose of a CURE; and 4) their engagement with five critical elements of a CURE. Students perceived variation both in the ability of their GTAs to create a supportive and comfortable learning environment, and in the emphasis their GTAs placed on certain lab objectives. Additionally, GTAs

appeared to impact student perceptions of the purpose of participating in CURE curriculum. While GTAs were divided in their perceptions of whether the CURE provided students with the opportunity to experience relevant discovery, students—regardless of their GTA—did not perceive that the opportunity for relevant discovery was an emphasized element of their CURE experience. Students in GTA-taught CUREs may therefore have vastly different experiences depending on their GTA, and may not equitably be experiencing the same research opportunities through their CURE experience.

Introduction

Participation in apprentice-based research experiences can be a highly beneficial experience for undergraduates in Science, Technology, Engineering, and Math (STEM) fields, offering wide-reaching advantages such as increased student motivation, interest in science, and retention in STEM fields (Carpi et al., 2017; Eagan et al., 2013; Laursen et al., 2010; Lopatto, 2007; Robnett et al., 2015; Seymour et al., 2004). However, opportunities to participate in such transformative experiences are restricted due to limited space and resources in faculty-led labs, and access to these opportunities can be unequitable (Bangera & Brownell, 2014). Universities have been called upon to address this issue for STEM students by increasing access to research experiences and providing opportunities for all STEM undergraduates to engage in research (Brewer & Smith, 2011; National Academies of Sciences, Engineering, & Medicine, 2015; National Academies of Sciences, Engineering, and Medicine, 2017; Olson & Riordan, 2012).

One approach to increasing opportunities for undergraduate participation in research is by integrating research-based courses into standard STEM curricula, especially at the introductory level where students may particularly benefit from the broad positive impacts associated with research participation (Bangera & Brownell, 2014; Graham et al., 2013; National Academies of Sciences, Engineering, & Medicine, 2015). A common model for integrating research into curriculum is via a course-based undergraduate research experience (CURE), where students generally participate in research projects under the guidance of an instructor and within the structure of a standard-enrollment laboratory course, often for the length of the academic term (Auchincloss et al., 2014). The CURE framework outlines that undergraduates should specifically engage in five elements essential to research: 1) use of multiple scientific tools and practices (*Scientific Practices*); 2) *Collaboration* both with other students and advanced scientists, who may be the course instructors; 3) *Iteration*, such that students have opportunities to revise their experiments and understand how scientific research builds off of previous research; 4) potential for *Novel Discovery* (i.e., experiments that address questions where the answer is unknown within the broader scientific community); and 5) *Broader Relevance*, such that the research problem is relevant and meaningful to other scientists or a local community who are not involved in the CURE (Auchincloss et al., 2014).

Like apprentice-based research, participation in CUREs results in benefits for students, such as increased scientific skills and understanding of the process of science, increased scientific self-efficacy, interest, and motivation in science, and increased retention in STEM (Brownell et al., 2015; Cooper et al., 2020; M. Harrison et al., 2011; Indorf et al., 2019; Reeves et al., 2018; Rodenbusch et al., 2016). Many of the studies demonstrating benefits for students participating in CUREs were conducted in classrooms taught by PhD-level faculty instructors, and neglect to consider an important logistical consideration of large-scale implementation of CUREs in introductory STEM classrooms: at 91% of research institutions graduate teaching assistants (GTAs), rather than faculty, provide the bulk of the laboratory instruction (Sundberg et al., 2005).

Students have different perceptions of faculty and GTA instructors of laboratory courses—students report that faculty instructors in general tend to be more enthusiastic, organized and prepared, and to have greater knowledge, while GTA instructors are less confident but create a more relaxed and laid-back environment (Kendall & Schussler, 2012). The expertise of an instructor may be particularly important in a CURE—indeed, faculty instructors report that three attributes critical in a successful CURE instructor are: 1) the ability to deal with the uncertainty of research; 2) a background in scientific research and specific proficiency in the area of research that is the focus of the CURE; and 3) a willingness to invest the necessary time and effort (Shortlidge & Brownell, 2016). GTAs, who are often novice teachers and researchers, may struggle in their capacity to meet these criteria and successfully teach a CURE. A study of GTAs teaching CUREs at one institution found that GTAs can feel unprepared to serve as research mentors, may perceive they lack appropriate expertise, and struggle with the time commitment required to teach a CURE (Heim & Holt, 2019). Student experiences in a GTA-taught CURE may therefore be very different as compared to a faculty-taught CURE: while some GTAs may have the expertise and motivation to capably teach a CURE, others may lack these attributes.

To date, little work has directly explored the impacts of individual instructors of CUREs. Some studies have reported preliminary evidence that students are indeed impacted by variability in the quality of their instruction—for example, one study found that students of a single PhD-level CURE instructor had a much lower proportion of students who could “think like a scientist” at the end of the term, compared to students of other instructors in the study (Brownell et al., 2015). Another study of nearly 800 students who enrolled in multiple CURE sections of the same course over a two-year period saw statistically significant variation in content knowledge gains for students across CURE sections, and the researchers suggested this variation could be attributed to the 30 different GTAs involved in teaching the CURE sections (Reeves et al., 2018). Further, a recent study explicitly focused on the individual pedagogical behaviors of GTA instructors of CUREs, and the impact their behavior has on student outcomes: Esparza and colleagues (2020) compared the pedagogical actions of four GTA instructors of CUREs with four GTA instructors of traditional laboratory courses, and found that CURE GTAs overall tended to engage more frequently in interactive classroom behaviors such as posing questions or one-on-one student interactions. However, there was significant variation in the instructional behaviors among the four CURE GTAs, and regardless of course type, GTAs who engaged more frequently in interactive instructor behaviors positively impacted students’ autonomous motivation, self-efficacy, and collaboration (Esparza et al., 2020). All three of these studies demonstrate that the behaviors of individual CURE instructors are likely variable and result in differential outcomes for students, but we are left without a clear understanding of the potential implications of instructor affect and actions on student experiences in a CURE.

Here we study the effects of individual GTAs on their students' experiences of the classroom environment, the relative importance of particular aspects of the CURE, and student perceptions of the reasons why their institution would offer CUREs. We additionally explore if student perceptions of CURE elements in their class align with the perspectives of their GTAs. Specifically, our work addresses four central research questions:

1. *How do undergraduate students perceive the environment of a CURE as facilitated by GTAs?*
2. *What do students think are the most and least important aspects of the CURE to their GTA, and does this vary by GTA?*
3. *Why do students think their university has them engage in a CURE in introductory biology, and does this vary by GTA?*
4. *How do student and GTA perceptions compare regarding the essential CURE elements, as specified by the CURE literature?*

We address these questions through a case study research design, comparing the experiences of students taught by different GTAs within a single large-enrollment introductory biology course. This allowed us to focus on the impacts of individual GTA instructors without introducing confounding contextual variables. We address our questions through multiple data sources collected from both students and their GTAs (outlined in Table 5-1), allowing for a deep and multi-faceted understanding of the experiences and perspectives of our study participants.

Methods

Pilot Data Collection

In Spring 2019, we conducted a pilot study in preparation for the study described throughout this manuscript. Our pilot study was conducted at a comprehensive university in the Western US with CUREs embedded throughout the undergraduate laboratory science curriculum. We collected data (including interviews, focus groups, course observations, and surveys) from eight GTAs teaching CURE labs and 119 of their students. While these data are not included in this manuscript, we used these pilot data to inform the design of our final study, including the crafting of reflection and interview questions, as described below.

Study Context

In fall 2019, we conducted an extensive study within a large-enrollment introductory biology laboratory course at a research-intensive university in the Pacific Northwest, where students co-enrolled in an introductory lecture course and a weekly CURE lab section. We used a multiple-case design, where each "case" encompassed the experiences and perceptions of a single GTA and that GTA's students (Yin, 2017). This study was approved by the Portland State University Institutional Review Board (no. 196388-18).

There were 20 lab sections consisting of approximately 20 students per section, each taught by one of nine GTAs (See Table 5-2 for the total number of sections and students taught by each GTA). The laboratory course used a network CURE design, where students participated in the HHMI SEA-PHAGES curriculum (Jordan et al., 2014). Students experience the five components expected for a CURE in that: they collaborate in groups (*Collaboration*) on a single term-long research project, where they collect soil samples and attempt to isolate and characterize bacteriophages (*Scientific Practices*), with the opportunity to repeat experimental steps when needed (*Iteration*). Due to the extensive diversity of soil bacteriophages, successfully isolated bacteriophages are presumed to be previously undescribed by scientists (*Novel Discovery*), and students then catalog their phages in a national database where the information has potential to be scientifically useful in the future (*Broader Relevance*).

In-Class Modified Focus Groups

Two researchers (ECG and EES) led group discussions with each lab section during Week 14 of the 16-week term to explore the student's perceived value of the CURE and their views on how their instructor supported their learning. These modified focus groups were designed based off of the "Small Group Analysis" protocol (Coffman, 1991; Mordacq et al., 2017), and occurred with students during class time, without the presence of the course instructors. Focus groups were audio and video recorded. Students earned two points of course credit for participating in the focus group and each of the surveys described below. They had the option to complete alternative assignments to earn the course credit if they chose not to participate in the study. During focus groups, students sat in their regular groups of 2-4 students per table, and 100% of students in attendance that week gave consent participate in the study (n=376 students, 20 lab sections).

Informed by findings from our pilot study, we iteratively designed three question prompts to facilitate discussion for the modified focus groups, and conducted face-validity checks with several undergraduates outside of our final study population to confirm that questions were clear and interpreted as intended (Taherdoost, 2016). We asked students the following three questions:

1. Please describe specific things that your instructor did that supported your learning and overall experience in this lab course.
2. Please describe what your lab classroom environment feels like (i.e., the mood, or general attitude of your lab mates and instructors). What made you feel this way?
3. Please describe any specific things your instructors could have done that would have improved your experience during this lab course.

During the focus group, researchers read the first prompt aloud, and gave students two minutes to reflect and write down their own thoughts. The students then had about three minutes to discuss their responses to the prompt with their small group. Finally, the researchers facilitated a full-class discussion, where researchers asked for a volunteer from each group to share their thoughts about the prompt, and frequently invited other students in the class to respond by elaborating, disagreeing, or confirming what their classmates were saying. This process was repeated for each of the three prompts.

Focus Group Analysis

To analyze focus group data, two researchers (ECG & JRC) watched the recordings of the modified focus groups together and individually made detailed notes and descriptions of the themes that emerged during whole-class discussions, resulting in preliminary codes. We then reviewed the preliminary codes together, and organized them into a codebook largely comprised of three broad categories: 1) strengths of the GTA or course; 2) indicators of a positive classroom environment; and 3) indicators of a negative environment or negative perceptions of the GTA or course. Each category included themes that grouped together more specific codes: for example, the theme "GTA is an engaging instructor" fell within the broad "strengths of the GTA/course" category. Within the "engaging instructor" theme were codes such as "GTA demonstrated investment in students/teaching" and "GTA had a positive attitude." The researchers then re-watched the recordings together, and using the final codebook, coded every focus group to consensus by discussing throughout the recording which codes were most appropriate.

We realized that many of the codes, independent of the theme in which they were grouped, were indicative of fairly distinct competency levels with regard to the GTA's management of the CURE and ability to support a positive learning environment. We therefore developed four additional themes to re-organize the codes as they related to a GTA's competency: "Above and Beyond," "Baseline," "Insufficient," and "Help!". To determine which of the codes aligned with each of these four themes, two researchers (ECG & JRC) individually considered each focus group code and made an independent judgment about the theme in which each code belonged. The researchers then compared their individual code-theme alignment decisions, and discussed to resolve any initial disagreements. The final GTA competency themes are described below:

1. ***Above and Beyond***. Codes in this theme indicated that the GTA supports student learning and creates a positive environment for learning. Examples of codes in within this theme include "GTA used inclusive/effective

teaching techniques" and "GTA was invested in students and their teaching."

2. ***Baseline***. Codes in this theme indicated that the GTA completes the basic tasks of managing a CURE. Examples include "GTA communicated expectations well" and "Most students understand the purpose of the CURE."
3. ***Insufficient***. Codes in this theme described minor critiques of the GTA that detracted from student learning. Examples include "Needed more instructional clarity or guidance for lab procedures" and "More organization needed from GTA."
4. ***Help!*** Codes in this theme described major critiques of the GTA in their capacity to support student learning. Examples include "Lack of engagement from GTA" and "GTA creates a stressful environment."

Not all of the codes from the focus group codebook fell into the four themes described above, and these unassigned codes were omitted from further analysis.

Each GTA taught two or three lab sections, and after our initial coding of each focus group, we compared coded segments for sections taught by the same GTAs. Qualitatively, we did not perceive notable differences between the individual focus groups of students with the same GTA, and we therefore decided to continue our analyses of the focus groups by GTA, rather than by class section. We summed the total code count by GTA for each of the above competency themes. To normalize code counts between GTAs who taught different numbers of sections, and to account for the fact that certain focus groups may have simply been more communicative than others, we then divided the total code count for each competency theme by the total code count of all of the competency-related codes that arose in each of the GTA's sections. This produced the relative frequencies of each competency category mentioned by students of each GTA.

Lab Learning Objectives Worksheet

Immediately after the class discussion described above, students were asked to individually complete a worksheet, which was designed to probe student perceptions of how their GTA prioritized potential lab learning objectives in the CURE. The worksheet consisted of 15 CURE lab learning objectives, such as "Students learn the importance of revising or repeating their work to improve the quality of their research" and "Students feel comfortable asking their instructors questions or discussing any problems." We developed the learning objectives informed by data collected in our pilot study (for full item list, see Appendix D.1). The worksheet asked students to indicate what they felt to be the three most and three least important objectives to their GTA in the CURE. They were asked to additionally provide a written rationale for why they choose what they indicated as the single most and single least important objective to their GTA.

Completed lab objectives worksheets were screened by researchers, and worksheets were excluded from analysis if they a) were not filled out correctly, or b) their response in the open-ended question implied they did not interpret the question as intended. Out of the 406 students who completed the worksheet, 376 responses were usable. We calculated the percent of total students who said that a given objective was among the top three most or least important to their GTA overall, and additionally disaggregated this information by GTA. This allowed us to identify similarities and differences in student perceptions of the importance of each lab objective by GTA.

Student Reflection Questions

During the eighth week of the term, we administered a constructed-response survey to students via an online survey platform. This survey included the question "Why do you think your institution wants students to participate in the research-based curriculum offered in this lab?"

We conducted initial/open coding on student's written responses to this question (Saldana, 2015), and two researchers developed and refined the initial list of codes while iteratively reading approximately 20% of the student responses. Researchers then individually coded all student reflection responses, including the 20% used in codebook development. Throughout the coding process, researchers met regularly to reconcile their individual coding decisions, and all final coding designations were discussed by both researchers to consensus. After coding was complete, we organized the codes in response to this question into two major themes: codes indicating that a student believed that their university implements CUREs due to student-centered purposes, and codes indicating that a student believed that their university implements CUREs due to non-student-centered purposes. We used Kruskall-Wallis tests to assess whether there were differences among GTA's in the proportion of their students who expressed these perceptions, and conducted post-hoc tests (Dunn's test with the Benjamini-Hochberg adjustment) to further explore potential differences.

End-of-term Laboratory Course Assessment Survey

We administered an end-of-term survey to students across sections via the online platform *Qualtrics* to quantitatively assess aspects of the student experience in the CURE and collect demographic information. This survey included the Laboratory Course Assessment Survey (LCAS), a 17-item instrument designed to measure CURE students' perceived participation in the essential the CURE elements of *Collaboration*, *Broader Relevance/Novel Discovery*, and *Iteration* (Corwin et al., 2015). We modified the frequency-related response options to better suit the weekly course format, as described by Goodwin and colleagues (2021; Appendix A.1).

Although there is evidence that the LCAS has produced valid data at other institutions with undergraduate students in CUREs (the population for which the LCAS was designed), different student populations may interpret survey items uniquely (Barbera & VandenPlas, 2011). We therefore used confirmatory factor analysis to test if the latent construct structure of the instrument functions as expected in our student population (Hancock et al., 2018). We tested a correlated three-factor model with *Collaboration*, *Broader Relevance/Novel Discovery*, and *Iteration* as separate latent factors, using a robust maximum likelihood estimator with the Satorra-Bentler correction to correct for potential non-normality in our item responses. After evaluating reliability and data-model fit statistics (Appendix D.2), we averaged the item responses within each scale and summed each student's total "score" for the LCAS, to create a single metric approximating the degree to which students perceived essential CURE elements. We conducted an ANOVA to assess if there were differences in LCAS scores of students taught by different GTAs, and used Tukey's HSD post-hoc tests to further explore potential differences. All statistical analyses described throughout this manuscript were conducted in R version 4.0.5, using the base, *lavaan* and *psych* packages (R Core Team, 2019; Revelle, 2021; Rosseel, 2012; RStudio Team, 2019).

GTA Interviews

We conducted end-of-term interviews with all nine GTAs involved in teaching the CURE lab sections. While most of the interview focused on understanding the different ways GTAs value teaching the CURE, we also asked GTAs about their perceptions of the presence of critical CURE elements in their class, as we were interested in how their responses would align with their students' perceptions of those elements. Further description of these interviews and analyses can be found in Goodwin et al., (2021; under review).

To analyze interviews, we developed an initial provisional codebook informed by our pilot study and previous work with GTA and faculty instructors of CUREs. Part of this codebook was specifically designed to capture GTA perceptions related to the elements essential to a CURE. Two researchers (ECG and JRC) read all GTA interview transcripts and generated new codes or clarified *a priori* codes. Both researchers used the final codebook to independently code each interview, and then reviewed and discussed each code designation to consensus. Finally, a single researcher read through each interview to check that coding was accurate and consistent across interviews.

Results

Participant information

Demographic information was collected from the end-of-term survey, which 383 students completed. Most students (70%) self-identified as female, and the average age was 19.8 years old (SD= 1.9 years). The majority of students were sophomores (56%), and over 90% of students reported no prior research experience. About 20% of students were pursuing a biology degree, and an additional 75% were pursuing other STEM degrees.

GTAs vary in their capacity to create a supportive classroom environment

The modified in-class focus group data allowed us to address our first research question, regarding how students perceive their CURE classroom environment. Within the focus groups, students of six GTAs (GTAs A through F) generally felt that their GTA was competent in promoting a positive classroom environment (“Above and Beyond,” or “Baseline” codes, Figure 5-1). Illustrative quotes below were sourced from the modified focus groups.

Students who perceived that their GTA was highly competent in creating a positive classroom environment (“Above and Beyond” instructors) described an appreciation for the “extra” effort their GTA put into the class, that their GTA clearly demonstrated investment in their learning, and that the lab experience was not just productive but also enjoyable. One student explained how their GTA was particularly understanding of student needs and willing to put extra effort in to accommodate their students:

> *"Our TA is helpful, especially if you need help with something and can't make it to a lab, or a make-up lab. They're willing to help you out because they understand that we're all busy. Everybody's busy, and helping each other out makes everyone's life a little bit easier." –A student of GTA B*

While students occasionally described instances where they perceived their GTA's competency in the CURE was "Above and Beyond" their expectations, students more frequently described positive attributes of their GTAs that we categorized as "Baseline." These codes described instances GTAs appeared to be meeting what might be expected of one teaching any course, such as clearly communicating their expectations of their students, clearly communicating the procedures and purpose of the course, providing thorough feedback to their students, and fostering a comfortable, productive, and collaborative environment. Students valued the effort their GTAs put in to making sure these baseline needs were met in their lab class:

> *"Our TA would always go over the protocol no matter what, so that was reassuring if you didn't quite understand it before coming to lab. I really liked that they would send a weekly email telling us what we could expect in lab and what assignments were due. There's a lot of things going on, so it was nice to have that."—A student of GTA E*

Students of all GTAs described instances where their GTA was "Insufficient" in meeting student needs—though students of some GTAs described many more instances of this than others (Figure 5-1). Students who found their GTAs to be "Insufficient" described needing more organization from their GTA, needing clearer expectations, that their GTA was confused about course material, or that they felt their GTA did not use class time well.

A common observation from students was that their GTA provided insufficient information for students to fully understand the purpose of what they were doing (and why) within their lab protocols:

> *"It would help if [our GTA] gave an explanation for which substances did what in the experiments, because I often found myself thinking: 'Oh, the instructions say [to add this] so I might as well add it' without understanding the purpose for adding it… I have no idea why we have to add this substance." – A student of GTA I*

These perceived "Insufficient" instances were often frustrating for students, but overall were minor and ultimately did not prevent students from succeeding in the CURE or feeling comfortable in the classroom. However, students also described more alarming instances where their GTAs failed to provide sufficient support for students to have a positive and beneficial experience in the CURE, which we coded as "Help!" (Figure 5-1). These students often described feeling that the classroom environment was uncomfortable or stressful:

> *"[Our GTA] gets really frustrated with us sometimes when we don't understand. We can ask them a question and then they'll try to explain it to us, but they'll just say stuff we really don't understand and then [our GTA] gets really frustrated with us. We feel how frustrated they're getting and there are definitely moments where I'm like: Are you going to shake me? Like 'Understand!'"—A student of GTA G*

While the majority of students ultimately spent more time discussing positive aspects of their GTA-taught CURE, students of three GTAs (G, H, and I) in particular described more "Help!" and "Insufficient" instances than "Baseline" or "Above and Beyond." The experiences of students taught by these the GTAs appear to be very different from the experiences of their peers, in that they do not report experiencing sufficient support from their GTA or feel like their classroom is a comfortable learning environment.

GTAs emphasize different aspects of the CURE

To address our second research question, we used the student lab objective worksheets, where students indicated which aspects of the course they perceived to be most and least important to their GTA. This allowed us to explore how a GTAs' differential interests or priorities may lead students to experience the CURE differently. Overall, given the options we provided, students perceived that developing basic lab skills, developing an understanding of the bacteriophage and host system, and being comfortable approaching the instructor with questions were prioritized by their GTAs (Figure 5-2, Panel A). In contrast, students reported that better understanding the content of the lecture portion of the course, learning if they are interested in a research career, and learning to troubleshoot problems independently were the least-emphasized course aspects (Figure 5-2, Panel A).

Perceptions of some lab objectives did not vary much by class. For example, most students regardless of GTA reported that experiencing the "process of research," "producing accurate data," experiencing "broader relevance" and "discovery" in the course, and learning "data analysis/interpretation" were not of particular importance to their GTA. However, GTAs widely influenced students' perceptions of other objectives (Figure 5-2, Panels B and C). For example, nearly 50% of GTA E's students believed that "collaboration" was one of the most important lab objectives to their GTA, while approximately 10% of GTA A and G's students listed collaboration as important (Figure 5-2, Panel B). This implies that GTA E is likely emphasizing collaboration—a critical CURE element—more than GTAs A and G, and students of different GTAs are therefore experiencing the CURE differently. Other areas of high variation between students' perceived experiences in a CURE are highlighted by the objectives included in Figure 5-2 (Panel B), where 50% of GTA H's students said that "approachability" was important to their GTA. One student explained how GTA H emphasized "approachability," explaining:

> *"I was confused a lot and [the GTA] always made the room feel comfortable to ask questions and be open talking with them."*

In contrast, only 5% of GTA I's students said that instructor approachability was important in their class, and many of GTA I's students emphasized that this was particularly unimportant—indicating they had a very different experience in the CURE:

> *"A lot of students are scared to ask questions from fear of getting [the GTA] mad and making us feel as if we know nothing."*

Students also perceived variance in the objectives that their GTAs emphasized the least (Figure 5-2, Panel C). For example, nearly 60% of GTA I's students reported that having students "enjoy" the lab was among the least important priorities for their GTA, while on average only 20% of students taught by other GTA's indicated this was specifically unimportant to their GTA.

GTAs influence student beliefs regarding the purpose of participating in the CURE

To address our third research question, we asked students to provide a written reflection response during an online survey to the question: "Why do you think your institution wants students to participate in the CURE?" In reviewing student responses to this question, we observed two distinct trends in student's perceptions of the purpose of participating in a CURE. Most students (78%) believed that their university engages students in CUREs for student-centered reasons (i.e., providing research experiences, helping develop lab skills and comfort in a lab setting, providing career/professional development, or increasing engagement with the course material). One student explained:

> *"I believe that our institution wants students to participate in research-based curriculum in Biology lab because it is much more interactive and intuitive than a normal lab. We are actually conducting research and learning the processes of research and doing it on our own."*

In contrast, 11% of students believed that their university employs CUREs in introductory biology labs solely for non-student-centered reasons (i.e., using students as a "free labor" resource to conduct research, using students to specifically further bacteriophage research, or because the CURE could bring more students or grant money to the institution), as demonstrated by the following quote:

> *"[Our institution uses CUREs] to make the school look better. It is a top tier research school and unfortunately that aspect is taking over a plethora of courses. Our participation allows for more data collectors."*

An additional 11% of students expressed both of these beliefs, acknowledging that while the CURE lab may exist to advance the university or scientific research, it also serves to benefit the students who participate in the CURE.

Kruskal-Wallis tests revealed that there were differences in the proportion of each GTAs students who believed the purpose of the CURE was student centered or not student-centered (Figure 5-4). Specifically, GTAs A and E had significantly higher proportions of students who believed the purpose of the CURE was student-centered as compared to GTA's C and F.

Students and their GTAs disagree on the presence of critical CURE elements in the classroom

We used student responses to the LCAS, student perspectives from the lab objectives worksheets and GTA interviews to address our final research question, where we compare student and GTA perceptions of the implementation of critical CURE elements (*Scientific Practices, Collaboration, Iteration, Novel Discovery/Broader Relevance*).

Descriptive statistics for each LCAS survey item revealed that no items display extreme deviations from normality (Appendix D.2), and we used a robust estimator in the CFA to account for moderate deviations from normality. Although all three subscales have acceptable internal consistency, fit indices for the final model fall at or slightly short of commonly used guidelines for "acceptable" model fit (for further discussion, see Appendix D.2). Although our survey data therefore should be considered with caution, we found that students of GTAs A, B, and C score significantly higher on the LCAS than students of GTAs G and H (Figure 5-4), implying that students in classes taught by GTAs A, B, and C perceive experiencing higher levels of the essential CURE elements of *Collaboration*, *Iteration*, and *Broader Relevance/Novel Discovery*.

Data from the lab objectives worksheets provided additional insight to student perceptions of individual CURE elements as fostered by their GTA: on average, 61% (SD=11.5%) of each GTA's students believe that learning *Scientific Practices* is among the most important aspects of the course to their GTA (Figure 5-2, Panel A; Table 5-3). While on average, fewer students report that *Collaboration* (mean=26.1% of each GTA's students, SD=12.9%) and *Iteration* (mean= 23.2%, SD=12.1%) are among the most important aspects to their GTA, the standard deviation for these statistics is still quite high

(Figure 5-2, Panel B). This implies that students taught by some GTAs perceive that these elements are important to their GTA, while students of other GTAs feel these elements are not emphasized (Table 5-3):

> *"Mostly everything in [the CURE] was overlooked, nothing was revised—it all seemed so unimportant and a waste of time and money."—Student of GTA H, perceiving their GTA's lack of emphasis on Iteration*

In contrast to the variation seen for *Collaboration* and *Iteration*, few students report that *Novel Discovery* (mean= 13.7%, SD=3.2%) and *Broader Relevance* (mean=16.1%, SD=2.5%) are among the most important elements of the course to their GTA—in fact, marginally higher proportions of students overall report that these elements are among the *least* important elements of the course to their GTA (Figure 5-2, Panel A). As indicated by the lower standard deviation in the percentage of each GTA's students who referenced *Novel Discovery* and *Broader Relevance*, students, regardless of instructor, perceived that *Novel Discovery* and *Broader Relevance* were not elements emphasized by their GTA. In summary, students perceived that *Scientific Practices* was important to their GTAs, *Collaboration* and *Iteration* were important to some of their GTAs, and *Broader Relevance* and *Novel Discovery* were least important to their GTAs (for supporting quotes, see Table 5-3).

We aligned these student perspectives of experiencing CURE elements with the perspective of their GTAs, which we explored through interviews. Most GTAs felt that students were exposed to multiple *Scientific Practices* and extensive *Collaboration* in the CURE (Table 5-3). GTA perceptions of experiencing *Iteration* in the CURE were slightly more variable—while most GTAs acknowledged that students experienced *Iteration* and some intentionally put extra effort into facilitating it (Table 5-3), GTAs D and I felt that iteration opportunities were limited:

> *"[Students] really only repeat their work if something hasn't worked...If they are successful, then they just keep moving on through these experiments, which I think is good because they get more excited about moving on and doing something new... I don't know that iteration is necessarily something that we do a lot of in this course."—GTA D*

GTAs varied the most in their perceptions that students experienced *Broader Relevance/Novel Discovery* through their participation in the CURE (Table 5-3). Five GTAs bought into the idea that students are experiencing this component of a CURE through their lab course, as students who successfully find a phage can contribute it to an online database:

> *"The students know they are finding a novel phage… But the big impact on society is that they get to submit it to a database, which scientists can pull from. [The phages] can be involved in phage therapy." –GTA C*

However, the remaining four GTAs felt this aspect of the course was limited, because they perceived that the scale of the potential *Novel Discovery* was very small, and/or the *Broader Relevance* to the greater scientific community was minimal:

> *"But are you discovering something that's going to be published? I think there is a deficiency with the SEA-PHAGES program and how it's implemented, not just here but in other schools too, where the discovery might be limited. [Students] can put [their phage] into the database, but who knows if anyone's going to look at it or use it in their own research that will lead to a publication." –GTA G*

In summary, while both GTAs and students agreed that opportunities for students to experience multiple *Scientific Practices* were present in the course, students and GTAs did not always equivalently perceive the opportunities for the other CURE elements. Although GTAs may perceive they are facilitating *Collaboration, Iteration,* and (sometimes) *Broader Relevance* and *Novel Discovery* in their courses, their students may not agree that these elements are emphasized by their GTAs.

Discussion

From this work, we have found that student experiences in what is intended to be the 'same' CURE can be very different, depending on their instructor. There are differences among the classroom environments, in the perceptions of what GTAs do or do not prioritize in the classroom, in the emphasis placed on critical elements of the CURE, and in student interpretations of the overall purpose of participating in a CURE.

Students who perceive a supportive learning environment experience more Collaboration, Iteration, and Relevant Discovery

Students perceived differing capacities among their GTAs to create supportive, positive learning environments, with the result that students of some GTAs feel encouraged and supported, while students of other GTAs feel anxious and uncomfortable. It has long been documented that student perceptions of instructor "misbehaviors", such as the behaviors we coded as "Insufficient" and "Help!" in our focus group analyses, detract from student's perceived experiences in a course (Kearney et al., 1991). Perceptions of instructor misbehaviors has also been hypothesized to contribute to student resistance to evidence-based learning pedagogy (Seidel & Tanner, 2013), and is linked to decreased student motivation to engage in a CURE (Goodwin, Cary, Therrien, et al., 2021; under review). Unsupportive and antagonistic instructors can increase student anxiety and stress (Reeve & Tseng, 2011; Schussler et al., 2021). A recent study comparing 472 students who were assigned to watch a recorded lecture taught either by a “standard” instructor or an “antagonistic” instructor found that students who were subject to the “antagonistic” condition reported significantly decreased affect towards content and willingness to engage in the class. This decreased affect moderated a decline in test scores in a content-based quiz for students in the antagonistic condition, providing evidence that a negative learning environment can lead to decreased affect and cognitive learning for students (Goodboy et al., 2018). On the other hand, students who perceive that their instructors engage in supportive behaviors are more likely to experience positive affective and cognitive outcomes (Baker & Goodboy, 2018; Cornelius-White, 2007; Goodwin, Cary, Therrien, et al., 2021 (under review); Seidel & Tanner, 2013; Wubbels & Brekelmans, 2005).

Student’s descriptions of specific elements of the CURE learning environment often referred to elements common to any classroom, rather than a CURE specifically—for example, that their GTA created a comfortable classroom environment, and clearly communicated expectations for the class. However, student LCAS scores (Figure 5-4) suggest that student perceptions of a supportive learning environment are correlated with perceptions of experiencing critical elements of a CURE. Students of GTAs who spoke the most about their GTA’s capacity to create a positive learning environment (such as GTAs A, B, and C; Figure 5-1), also reported the highest perceptions of engaging in *Collaboration, Iteration,* and *Broader Relevance/Novel Discovery* (Figure 5-4). Students who indicated that their GTAs did not create supportive lab environments (such as GTAs G, H, and I; Figure 5-1) scored lowest in their perceptions of the same critical CURE elements (Figure 5-4). Variation in the supportive environment created by individual GTAs likely therefore results in variation in experiencing the affective and cognitive outcomes that are meant to be provided through the CURE, as seen in other studies (Baker & Goodboy, 2018; Cornelius-White, 2007; Goodwin, Cary, Therrien, et al., 2021). This potentially also perpetuates inequitable experiences of undergraduate research: positive perceptions of the lab environment are linked to increased persistence for students participating in apprentice-based undergraduate research experiences, and students who experience a negative lab environment are more likely to leave their research experiences (Cooper, Gin, et al., 2019). As for students in apprentice-based research experiences, it is possible that perceptions of the lab environment in the CURE could impact students' interest in pursuing research experiences.

GTAs create different experiences for their students by emphasizing different learning objectives

In addition to perceiving differences in the overall lab environment created by their GTA, students perceive that their GTAs vary in the emphasis placed on specific learning objectives (Figure 5-2). It is a logical assumption that individual instructors will vary greatly in their behavior and communication in their classrooms. Indeed, variation in instructor behavior has been documented in analyses of introductory biology classrooms using the Instructor Talk framework, which allows for systematic documentation and analysis of the non-content communication instructors relate to students, such as talk that builds interpersonal relationships, establishes classroom culture, explains pedagogical choices, and negatively phrased talk (Harrison et al., 2019; Seidel et al., 2015). Fewer studies specifically focus on variation in GTA behavior when teaching lab sections of the same course: a case study analyzing video recordings of three GTAs teaching physics recitations found that instructor discourse and behavior varied, such that one GTA was likely more effective at fostering student agency in the course as compared to the other two GTAs (Spike et al., 2012). In addition to varying in their non-content behaviors, GTAs differ in their documented pedagogical behaviors: a study of eight GTAs, four of whom taught non-CURE laboratory sections and four of whom taught CURE sections all associated with the same introductory biology course, found that GTAs vary in their pedagogical instructional behaviors, even when teaching the same type of lab class (Esparza et al., 2020). We expect that some of the variation that students perceive about what are most or least important objectives (Figure 5-2, Panels B and C) is a direct reflection of the effort GTAs put towards achieving those lab outcomes. Variance in instructor behaviors inevitably impact student experiences in the classroom—the high among-GTA variation we observed in student perceptions of lab objectives such as collaboration, iteration, and independent troubleshooting indicate student experiences with these elements could be significantly different, depending on their GTA.

GTAs communicate different messages about the purpose of a research-based curriculum

In addition to impacting student experiences in their class, GTAs can impact their student's overall understanding of why they are participating in research-based curriculum. We found significant differences in the proportion of individual GTAs' students who believed that they were participating in their research-based curriculum for student-centered purposes (i.e., to benefit students) or for non-student-centered purposes (i.e., to benefit the university or use students as “free labor” in advancing research projects). We hypothesize these differences may be due to instructor talk and the variances in messages that GTA’s convey to their students (Harrison et al., 2019; Seidel et al., 2015), such that certain GTAs focus more on explaining the pedagogical choice to implement a CURE and the student-centered advantages of participating in a CURE. Other GTAs may actively engage in negative instructor talk, such as expressing doubt in the pedagogical advantages of the curriculum (Harrison et al., 2019). Instructors who fail to sufficiently explain the pedagogical advantages of the CURE may lead to decreased student buy-in and increased student resistance to engaging in the CURE (Seidel et al., 2015).

Students and their GTAs both recognize the prevalence of Scientific Practices, Collaboration, and Iteration in the CURE

Although there was some variation in student perceptions of how important these elements were to their individual GTAs, students overall identified that the CURE elements of *Scientific practices, Collaboration,* and *Iteration* were among the lab objectives most important to their GTAs (Figure 5-2, Table 5-3), and GTAs generally agreed that these elements were prioritized in the class (Table 5-3). Given that the intention of a CURE is to provide students with a research experience that includes elements of *Novel Discovery* and *Broader Relevance*, we were surprised that the top two lab objectives students reported as most important to their GTAs were “Scientific Practices” and “Understanding the bacteriophage system.” Previous studies have shown that students rarely have a clear understanding of the purpose of their participation in traditional scientific laboratory settings, and the ones that do generally perceive that the purpose is simply to "follow instructions" or "get the right answer" (Hofstein & Lunetta, 2004). The high priority students in our current study placed on experiencing "Scientific Practices" and "Understanding the bacteriophage system" could be interpreted similarly to the broader objectives of "following instructions" or "getting the right answer," because students often experienced scientific practices through following the instructions of their GTA or lab protocols. Additionally, students were given GTA-led lectures and quizzes on both their research methods and the bacteriophage-host context of their project, which likely reinforced the importance of these elements within the CURE curriculum.

Although students reported experiencing *Iteration*, they also largely felt that "independent troubleshooting" was unimportant to their GTA (Figure 5-2). While "independent troubleshooting" on its own is not one of the five elements defined in the CURE, there is an expectation that students engage in this activity as part of the experience of *Iteration:* as stated by Auchincloss and colleagues (2014), "students learn by trying, failing, and trying again." It was therefore striking that so many students said that "independent troubleshooting" was among the least important objectives for their GTAs (Figure 5-2, Panel A). This may be an indication that CURE GTAs, like inquiry GTAs, have difficulty in providing space for students to learn through failure (Gormally et al., 2016). Recent work has found that experiences in failure in a CURE is often a beneficial experience for students, and can increase student buy-in, resiliency in navigating obstacles, and understanding of the nature of science (Gin et al., 2018; Goodwin, Anokhin, et al., 2021). Limiting opportunities to learn through failure will therefore reduce the benefits that a CURE curriculum intends to offer students.

GTAs and students are uncertain of the Broader Relevance and Novel Discovery in the SEA-PHAGES curriculum

While students perceived that essential CURE elements of *Use of Scientific Practices, Collaboration*, and *Iteration* were generally prioritized by their GTAs, few students felt that elements of *Broader Relevance* or *Novel Discovery* were priorities within the classroom (Figure 5-2, Table 5-3). The failure of students to perceive these elements as important could be a consequence of two possible phenomena: 1) students are failing to recognize the presence or importance of *Broader Relevance* and *Novel Discovery*; and/or 2) GTAs are failing to emphasize or effectively scaffold the elements of *Broader Relevance* and *Novel Discovery* in their classes.

There is evidence to support both of the phenomena listed above. In addition to having limited perceptions of the purpose of their laboratory courses (Hofstein & Lunetta, 2004), students and instructor perceptions of instructional practices in a course are not strongly correlated, as reveled by a large-scale study of 878 students in 54 different inquiry-style laboratory courses (Beck & Blumer, 2016). Researchers found that when there was a correlation between student and instructor perceptions (for the instructional practice categories of "scientific synthesis" skills and "instructor-directed teaching"), instructor accounted for less than 25% of the variation in student responses (Beck & Blumer, 2016). A second study found that physics students are unaware of specific concepts that were taught in their class, even when instructors and expert observers report that those concepts were addressed (Hrepic et al., 2007). It therefore seems very possible that students could fail to recognize the presence of *Broader Relevance* and *Novel Discovery* that has been scaffolded into the CURE.

However, students were not the only ones who failed to recognize the presence of *Broader Relevance* and *Novel Discovery* within their curriculum: several GTAs also questioned the presence of these elements within the CURE. SEA-PHAGES scaffolds these elements such that students isolate a phage, which is presumed to be novel due to the wide diversity of bacteriophages (*Novel Discovery*), and archive information about the phage in an online national database, where the information could potentially be used by other scientists (*Broader Relevance*). While all GTAs were aware of the novelty of the isolated phage and the contribution of information to the online database, nearly half of the GTAs still said that these elements are insignificant in the curriculum (Table 5-3). Therefore, it is likely that GTAs had difficulty emphasizing *Broader Relevance* and *Novel Discovery* for students, because they felt that these elements were not sufficiently developed in the curriculum itself.

Are the elements of Broader Relevance and Novel Discovery sufficiently scaffolded within the SEA-PHAGES curriculum?

The failure of students to recognize the elements of *Broader Relevance* and *Novel Discovery* is inconsistent with the experiences of students of independent CUREs, who both recognize *Broader Relevance* and *Novel Discovery* and experience positive affective outcomes associated with these elements (Cooper, Blattman, et al., 2019; Goodwin, Anokhin, et al., 2021). Given that the primary difference in instructional framework of a CURE as compared to other laboratory course structures are the elements of *Broader Relevance* and *Novel Discovery* (Auchincloss et al., 2014; Brownell & Kloser, 2015; Goodwin, Anokhin, et al., 2021), we found it notable that so many students reported that these were unimportant objectives in their class (Figure 5-2). Since both students and instructors perceive that these elements are lacking in the curriculum, we question whether students who participate in the SEA-PHAGES curriculum are truly experiencing a CURE, as defined by Auchincloss et al., (2014).

Implementation of the SEA-PHAGES curriculum varies widely, and students who participate in this curriculum at other institutions may have the opportunity to participate in activities not available to the students in our study, such as a second term of research conducting bioinformatic analyses on their isolated phage, or participation in local or national meetings (Jordan et al., 2014). However, many institutions do not have the capacity to provide all of these elements of the SEA-PHAGES curriculum to students, and there is evidence of positive student outcomes from participating in just the phage discovery portion of the course, as students in our study experienced (Staub et al., 2016). While students clearly benefit from the SEA-PHAGES curriculum (Hanauer et al., 2017; Jordan et al., 2014; Staub et al., 2016), future research should explore whether *Broader*

Relevance and *Novel Discovery* are adequately scaffolded such as to meet the expectations of a CURE. It is possible that students participating in the SEA-PHAGES curriculum are actually experiencing an advanced inquiry-style course—which can still benefit students and allow for students to experience elements of authentic research (Cooper et al., 2019; Goodwin et al., 2021)—rather than a true CURE.

Limitations

This work demonstrates the potential range and variation of experiences that students may have when taught by different GTAs in a single CURE. We therefore encourage practitioners and researchers to be cognizant of the types of impacts that individual GTAs may have on their student's experiences in a CURE. However, the findings from this study represent the experiences and perspectives from a single set of GTAs and their students during one term of an introductory biology lab course at one institution. It is likely that the experiences and perceptions of students and instructors would be different given other variables, such as course level (upper vs lower division), institutional contexts, training and selection of GTA instructors, and variation in CURE curriculum. Researchers and educators should continue to consider how these variables may impact both students and GTAs teaching CUREs within other course contexts.

Despite evidence that the LCAS survey functions well in similar populations at other institutions (Corwin et al., 2015, 2018; Goodwin, Anokhin, et al., 2021; Sathy et al., 2020), our data-model fit statistics indicate that there may be some issues with the LCAS item functioning for our student population at this institution. We decided to continue to include the LCAS data in this manuscript because the fit, while below recommended cutoffs, is still reasonable, and the trends we see in the LCAS data align with the trends seen in other data used in this manuscript.

Conclusions

In implementing CUREs in undergraduate biology coursework, there is an implicit assumption that we are providing a structured, equitable research experience for students. However, depending on both the curriculum and the instruction, students may fail to sufficiently experience the critical elements defined in the CURE framework. Researchers and educators should continue to consider the presence of *Broader Relevance* and *Novel Discovery* within the curriculum and consider ways to strengthen these elements as necessary if there is a need to engage students in a 'true' CURE rather than an advanced inquiry laboratory course.

Patterns of variation in student perceptions of the lab environment and course intentions show that students of different GTAs fundamentally have different experiences. Some GTAs likely are facilitating learning environments more conducive to achieving the benefits intended for students by participating in a CURE, while other GTAs are not. Equity of student experiences in GTA-taught CUREs should therefore be a concern of future researchers. Are students benefiting from a CURE when taught by a GTA (or any instructor) who creates a negative learning environment, or fails to understand or emphasize critical CURE elements? As differences in instruction clearly exist in GTA-taught laboratory courses, researchers should also consider GTA as a variable in future analyses exploring student experiences in laboratory classes.

Efforts to provide professional development opportunities to better prepare GTAs to effectively facilitate research-based curriculum for their students are needed. Training should focus not only on the technical aspects of teaching scientific tools and processes, but also on creating supportive learning environments for students, facilitating effective student engagement with the critical elements outlined in the CURE framework, and using positive instructor talk to explain the purpose of participating in research-based curriculum.

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Figures and Tables

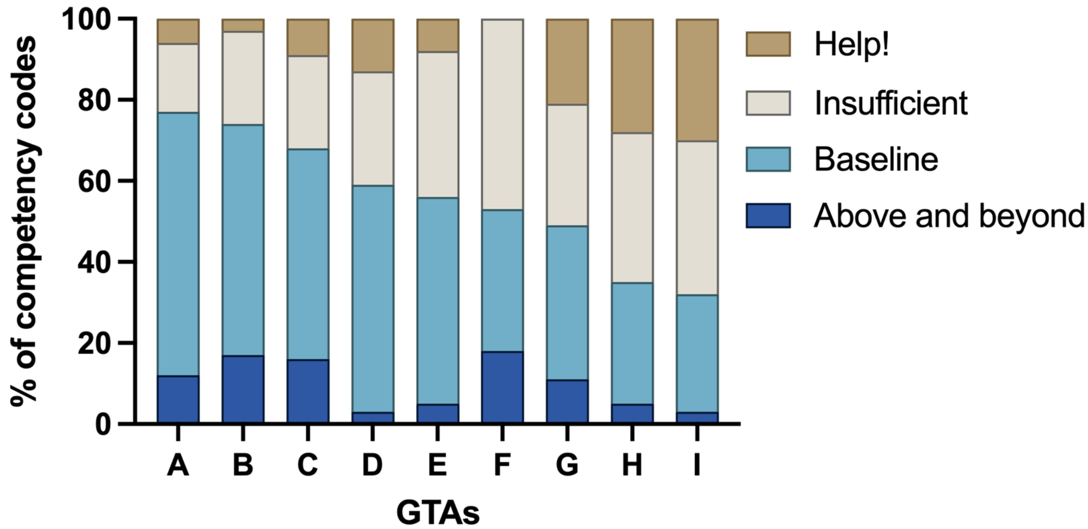

Figure 5-1. *GTAs varied in their ability to create a positive learning environment*

We coded student descriptions of their GTA's competency during focus groups, and compare the frequency at which students describe their GTA's actions as highly competent ("Above and beyond"), meeting expectations ("Baseline"), not meeting expectations ("Insufficient") or highly incompetent or destructive of the classroom environment ("Help!")

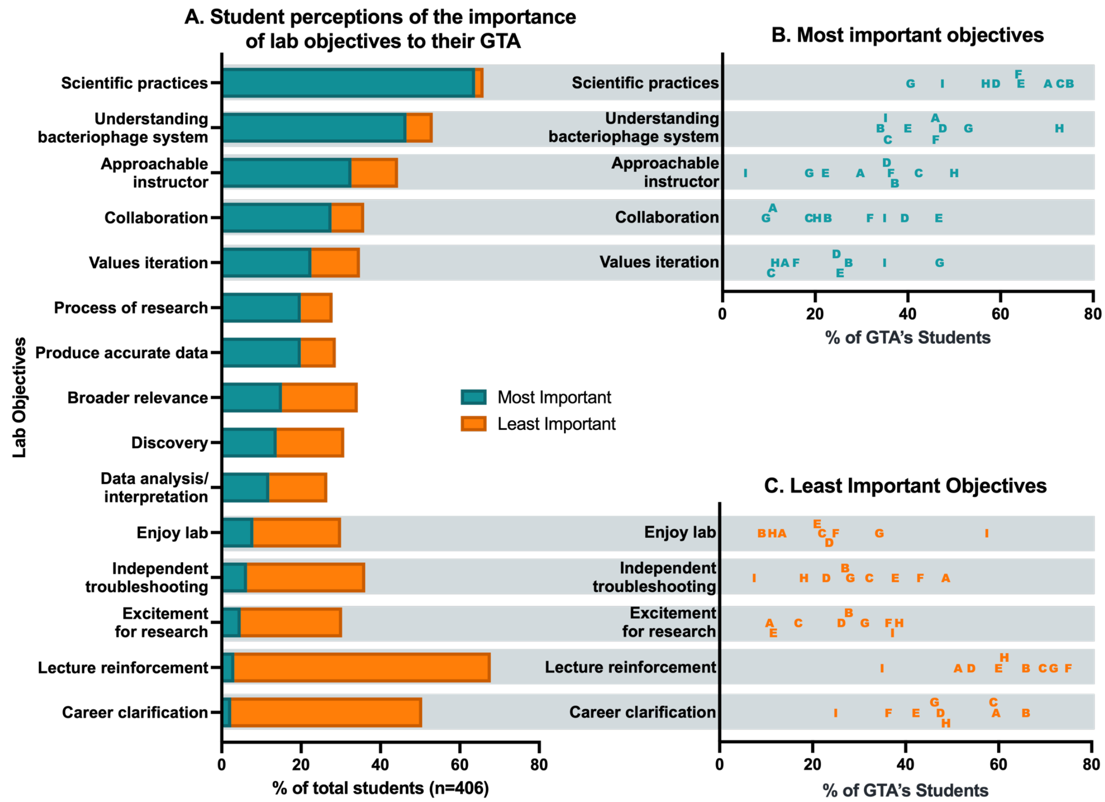

Figure 5-2. *GTAs emphasized different lab objectives*

Panel A (left) shows the percent of students overall who reported that each lab objective was among the most (blue bar) or least (orange bar) important objectives for their GTA. Letters in Panels B and C identify the individual GTAs, demonstrating how student perceptions of the relative importance of these objectives vary by GTA. Panel B (top right) shows the percent of each GTAs' students who reported that specific objectives were among the most important to their GTA. Panel C (bottom right) shows the percent of each GTAs' students who reported that specific objectives were among the least important to their GTA.

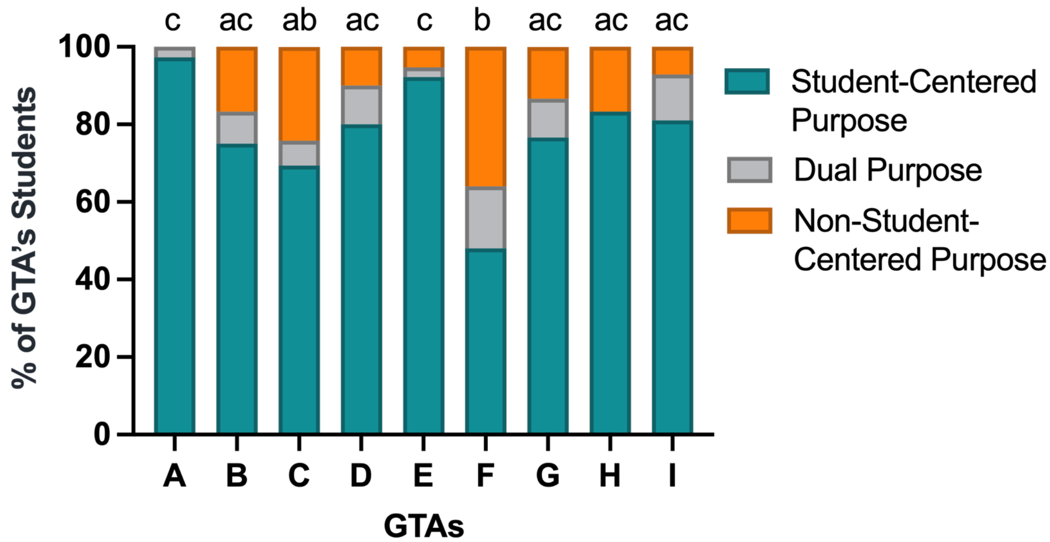

Figure 5-3. *GTAs impact how students perceive the purpose of participating in a CURE*

We coded student reflection questions to identify the proportion of each GTA's students who believed that the university employed CUREs in introductory biology labs for student-centered purposes or non-student-centered purposes. Lowercase letters above bars indicate significant differences in the proportion of a GTA's students who believe that the CURE has a non-student centered purpose: bars that do not share a common letter indicate a significant difference in perceived purpose for students of the indicated GTA

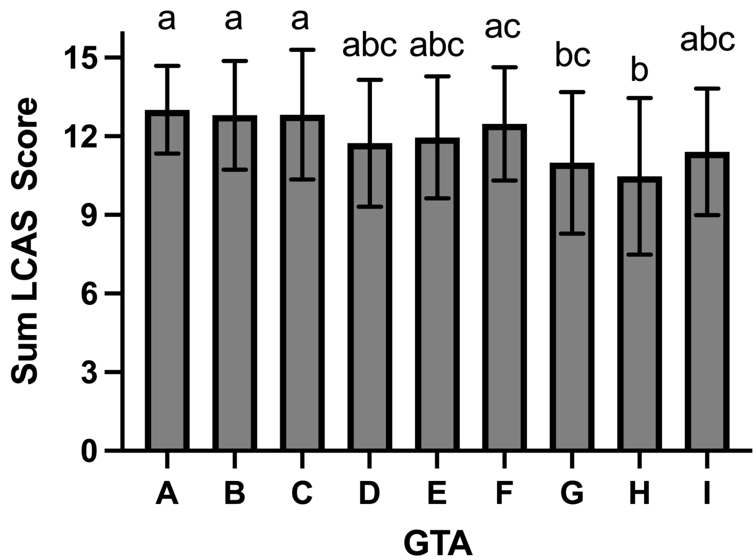

Figure 5-4. *GTAs impact student perceptions of essential CURE elements*

Bars represent the summed average (± 1 SD) of the three constructs measured in the LCAS (Collaboration, Iteration, and Broader Relevance/Novel Discovery) for students of each GTA. Lowercase letters above bars indicate significant differences in summed LCAS scores: bars that do not share a common letter indicate a significant difference in LCAS scores for students of the indicated GTA. Students of GTAs A, B, and C perceive significantly higher CURE elements in their classes than do students of GTAs G and H.

Table 5-1. *Data collection summary*

Data Source	Participants	Administration	Associated Research Questions [a]
In-Class Modified Focus Group	n= 406 (students)	Late-term, in-person and during class	1
Lab Objectives Worksheet	n= 376 (students)	Late-term, in-person and during class	2 & 4
Demographics and Laboratory Course Assessment Survey	n= 383 (students)	End-of-term, via an online survey platform	4
GTA Interviews	n= 9 (GTA instructors)	Late-term, in-person	4
Student Reflection Questions	n= 351 (students)	Mid-term, via an online survey platform	3

[a] Study Research Questions: 1) How do undergraduate students perceive the environment of a CURE as facilitated by GTAs? 2) What do students think are the most and least important aspects of the CURE to their GTA, and does this vary by GTA? 3) Why do students think their university has them engage in a CURE in introductory biology, and does this vary by GTA?
4) How do student and GTA perceptions compare regarding the essential CURE elements, as specified by the CURE literature?

Table 5-2. *Number of sections taught and student study particpants for each GTA*

GTA Identifier (n=9)	# of Sections Taught (n=20)	# of Student Participants (n=434)*
A	2	45
B	2	39
C	3	69
D	3	64
E	2	47
F	2	44
G	2	35
H	2	46
I	2	45

* Total number of participants at the start of the term, which does not account for enrollment attrition throughout term.

Table 5-3. *Alignment of student and GTA perceptions of the importance of individual CURE elements*

CURE Element	Students' perceptions of importance to GTA	GTAs' perceptions on presence in CURE
Scientific Practices	**Important to All GTAs** *"[Our GTA] has clearly demonstrated how to perform basic lab techniques, and the importance of why they need to be done correctly. They also stated that these techniques will be used in further research*." –Student of GTA C, perceiving use of scientific practices	**Present in CURE** *"They do get exposed and engaged in multiple scientific practices, doing different kinds of techniques [in the CURE]. Imagine a kid of 19 or 20 doing so many kinds of techniques. It's amazing."* – GTA B, perceiving use of scientific practices
Collaboration	**Important to Some GTAs** *"[Our GTA] was very clear that this lab was supposed to be collaborative and we are supposed to gain knowledge from our classmates."* –Student of GTA E, perceiving collaboration	**Present in CURE** *"They are working with partners and peers. [Teamwork is] very important... They are discussing with other students, sharing ideas, getting ideas."* – GTA E, perceiving collaboration
Iteration	**Important to Some GTAs** *"[Our GTA] always says that the more we do it, the more we'll understand, and the better we'll get at it."* –Student of GTA G, perceiving iteration	**Mostly Present in CURE** *"For most of the semester they're just repeating the same thing to try to find phage...I allow students to revise their work once I give them their feedback to further improve their learning gains. Then I also push them all to think about how things are connected. I really try to hit iteration with my feedback."* – GTA G, perceiving iteration
Broader Relevance/ Novel Discovery	**Not very important to GTAs** *"I highly doubt that the simple bacteriophage labs we do will create a huge influx in the science world. [Our GTA] does not [teach us] this" –Student of GTA D, perceiving lack of relevant discovery*	**Presence Varies by GTA** *"The bacterial hosts are not something that anyone cares about... if we were to do [the CURE] with a different host bacterium that could have actual medical relevance [students would experience relevant discovery]."* –GTA D, perceiving lack of relevant discovery

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Chapter 6

Graduate Teaching Assistants Impact Student Motivation and Engagement in Course-based Undergraduate Research Experiences

In prep for submission:

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Abstract

Numerous benefits can result from students participating in undergraduate research, and efforts to provide sufficient opportunities for involvement in research have sparked an increase in implementation of course-based undergraduate research experiences (CUREs) in introductory biology labs. Graduate teaching assistants (GTAs), who often teach introductory biology labs, are consequently often asked to mentor and support their students' research projects in a CURE. We know little about how GTAs perform in their roles as a CURE research mentors, or how their mentorship quality impacts students. We conducted interviews with 25 students taught by nine different GTAs in a single CURE, and used self-determination theory to explore how students' autonomous motivation to engage in the CURE is impacted by their perceptions of their GTA's support. Highly motivated students were more likely to experience *Autonomy, Competence,* and *Relatedness* in the CURE, and to perceive that their GTAs were highly supportive of these elements. Perceiving that one's GTA is unsupportive of *Autonomy, Competence,* and *Relatedness* appears to be a barrier to students experiencing high autonomous motivation in the CURE. Student motivation was correlated with perceptions of experiencing critical

research elements offered in the CURE. Students who experienced lower autonomous motivation in the course were less likely to report engaging in elements such as collaboration, iteration, and relevant discovery. We propose that GTAs mediate student motivation in a CURE: students who perceive that their GTAs are supportive may subsequently experience higher autonomous motivation and be more likely to experience specific research elements in their class. Students with GTAs who do not offer sufficient support in the classroom are more likely to experience low motivation in the class, and consequentially may fail to experience the research elements provided by a CURE.

Introduction

For undergraduates in science, technology, engineering, and math (STEM) fields, participating in research as an undergraduate is often a transformative experience, with documented positive impacts such as increasing student motivation, interest, and retention—particularly for students who are traditionally underrepresented in STEM fields (Carpi et al., 2017; Eagan et al., 2013; Laursen et al., 2010; Lopatto, 2007; Robnett et al., 2015; Seymour et al., 2004). Therefore, several national calls have been made to expand access to research and provide research opportunities for all undergraduates in STEM fields (Brewer & Smith, 2011; National Academies of Sciences, Engineering, & Medicine, 2015; National Academies of Sciences, Engineering, and Medicine, 2017; Olson & Riordan, 2012). Traditional undergraduate research experiences follow an apprenticeship model, where students work within a faculty member's lab and assist with research projects under the mentorship of the faculty researcher or other members of the lab (Seymour et al., 2004). However, there are insufficient opportunities for all biology undergraduates to be placed into traditional apprentice-based research experiences within faculty-led labs, and there are barriers that create inequities in access and selection to participate in the limited apprentice-based opportunities that do exist (Bangera & Brownell, 2014).

In efforts to expand participation in undergraduate research experiences, universities are increasingly implementing course-based undergraduate research experiences (CUREs), particularly in their biology laboratory curriculum (National Academies of Sciences, Engineering, & Medicine, 2015). In CUREs, students participate in a research experience within the setting of an instructor-taught laboratory course, typically for the length of the academic term (Auchincloss et al., 2014). CUREs aim to engage students in the same elements they would experience in a traditional apprentice-based research experience: 1) students use multiple scientific tools and practices (*Scientific Practices*); 2) students collaborate with their peers and instructors (*Collaboration*); 3) students engage in iteration by revising and building on their experiments or the experiments of others (*Iteration*); 4) students are conducting research projects that have the potential for novel discovery (*Novel Discovery*); and 5) the research that students conduct is broadly relevant, with implications that could be relevant to a scientific or local community outside of the classroom (*Broader Relevance;* Auchincloss et al., 2014). *Novel Discovery* and *Broader Relevance* are closely related concepts that are sometimes collapsed into a single element (*Broadly Relevant Novel Discovery*). It is the presence of *Broadly Relevant Novel Discovery* that truly distinguishes a CURE from other inquiry-type laboratory courses, where students may also engage in student-driven experimentation, though with little expectation of producing potentially publishable work (Auchincloss et al., 2014; Brownell & Kloser, 2015; Cooper et al., 2017, 2019; Goodwin, Anokhin, et al., 2021). Participation in CUREs offers undergraduates many of the same benefits as traditional research experiences, including increased scientific and data analysis skills, improved understanding of the process of science, increased self-efficacy and interest in science, and increased retention in STEM fields (for examples, see Brownell et al., 2012, 2015; Harrison et al., 2011; Indorf et al., 2019; Rodenbusch et al., 2016; Shapiro et al., 2015). These experiences may be particularly impactful for students traditionally underrepresented in STEM fields (Cooper et al., 2020; Ing et al., 2021; Reeves et al., 2018).

To further reduce inequities in who gets to participate in research, and amplify benefits for undergraduates, there is growing interest in integrating CUREs into introductory courses—the point when students are most susceptible to leaving STEM fields (Bangera & Brownell, 2014; Graham et al., 2013; National Academies of Sciences, Engineering, & Medicine, 2015). However, one factor critical to implementing CUREs *en masse* has been largely ignored: graduate student teaching assistants (GTAs), rather than PhD-level faculty instructors, are providing the majority of laboratory instruction at over 90% of research-intensive institutions, with only 24% of introductory labs at large institutions being taught by tenure-track faculty (Sundberg et al., 2005). Previous studies on CUREs neglect the efficacy of using GTA instructors. In fact, several were conducted in CURE classrooms explicitly taught by PhD-level instructors rather than graduate or undergraduate teaching assistants (i.e., Brownell et al., 2012, 2015; Indorf et al., 2019; Rodenbusch et al., 2016). The structure and intention of CUREs often necessitates that the instructor's role shifts, such that instead of being a content-deliverer or overseeing students as they complete traditional lab activities, CURE instructors act as research mentors and guides for their students. Faculty and GTA instructors of CUREs have described that this shift in instructional role can be a challenge in teaching these labs, along with other CURE-specific challenges such as an increased time and work investment, and dealing with the uncertainty of research in real-time with their students (Goodwin et al., 2021; Heim & Holt, 2019; Shortlidge et al., 2016, 2017). Large-scale expansion of CUREs into introductory biology laboratory courses will therefore necessitate a consideration of the capacity of GTAs to expand their instructor role in order to effectively serve as CURE research mentors.

Change initiatives for the adoption of evidence-based teaching methods, as will be expected from CURE GTAs, are not easy to foster. A review of change strategies found that a significant barrier to adjusting one's pedagogical approach can occur when the existing beliefs of instructors contradict the philosophy of the instructional practice they are engaging in (Henderson et al., 2011). It is possible that some GTAs of CUREs will not fully understand or buy into the philosophy of why researchers and educators are integrating CUREs into introductory biology curriculum, and other GTAs may not be sufficiently supported in their efforts to learn how to effectively teach a CURE. In either of these scenarios, we may ultimately fail to provide undergraduate students with meaningful research experiences through GTA-taught CUREs. There is evidence that GTAs do indeed face these barriers: GTAs teaching both CUREs and inquiry-based courses may assume that introductory students are unprepared to succeed in CURE or inquiry labs, and consequently GTAs teaching these courses can have trouble allowing students to take control of their own learning (Gormally et al., 2016; Heim & Holt, 2019; Kurdziel et al., 2003). Further, graduate students—even those who are interested in evidence-based teaching—may struggle with adopting evidence-based teaching practices. This can be due to a variety of barriers including: limited access to training; the perception that evidence-based teaching methods are not compatible with the course a GTA is teaching; or the perception—perpetuated within academic culture for decades—that teaching should not be the focus of graduate studies (Connolly et al., 2018; Goodwin et al., 2018; Lane et al., 2019; Luft et al., 2004; Schussler et al., 2015; Shortlidge & Eddy, 2018). These barriers may result in variability among GTAs' capacity to perform as CURE research mentors, and impact the quality of GTA mentorship in a CURE, which will in turn, impact the experiences of the undergraduate students. We sought to conduct an in-depth exploration of how instructor behavior impacts student experiences in a CURE, and how these perceptions of instructor behavior may influence student motivation in the course.

Self-Determination Theory

We used self-determination theory (SDT, Ryan & Deci, 2000) to explore how student motivation, experiences, and perceptions of participating in a CURE are impacted by their GTA instructors. SDT has been used abundantly over the past several decades to explore student motivation in a wide variety of learning contexts, including K-12 education, undergraduate education, and adult informal education (for examples, see Glynn et al., 2011; Hagay & Baram-Tsabari, 2015; Jones et al., 2017). SDT provides a taxonomy of motivation that organizes motivation types on a continuous scale of self-determined behavior: *Amotivation* (lack of value and motivation) and *Strictly External* motivation (compliance with external rewards/punishments) are indicative of low autonomous (self-determined) behavior, while *Identified* extrinsic motivation (personally recognizing utility value) and *Intrinsic* motivation (interest, enjoyment, and satisfaction) progressively indicate increased self-determined and autonomous behaviors (Figure 6-1; Ryan & Deci, 2000). A recent metanalysis examining data from 273 published studies found that autonomous (*Identified* and *Intrinsic*) forms of motivation are positively correlated with several student outcomes, including effort, engagement, affective outcomes, and academic performance (Howard et al., 2021). The correlation between autonomous motivation and student outcome is likely due to increased effort and investment on the part of autonomously motivated students (Ryan & Deci, 2020). For students in a CURE setting, we predicted that *Amotivation* and *Strictly External* motivation may present as a lack of interest in engaging in the course, such that students are unwilling to do more than what is strictly required of them to get the grade they desire. Alternately, students who have *Identified* and *Intrinsic* motivation towards the CURE are likely more willing to invest their time and effort in the course.

SDT further posits that the three basic needs of *Autonomy, Competence* and *Relatedness* must be met in order to support students' autonomous, self-determined motivation (Figure 6-1; Ryan & Deci, 2000, 2020). *Autonomy* is experienced by students with a sense of ownership and internal control over one's experiences. *Competence* is experienced by students who feel that they are appropriately challenged and have a sense that they can succeed and grow. Finally, *Relatedness* is experienced by students who feel a sense of belonging, support, and connection to their environment (Ryan & Deci, 2000, 2020). Numerous studies have identified positive relationships between student outcomes and environments that support their basic needs (reviewed in Ryan & Deci, 2020). These studies often focus on the impacts of providing *Autonomy*-support for students, which is often accompanied by also providing *Relatedness* and *Competence* support. For example, a study of 137 students in undergraduate organic chemistry workshops taught by 42 advanced undergraduate or graduate students found that perceiving that one's instructor supported student *Autonomy* positively impacted both course grade and affective student outcomes such as intrinsic motivation and feelings of competence—particularly when students entered the class with low initial autonomous motivation (Black & Deci, 2000).

Research Questions

We expect that a GTA's efficacy in supporting their students' *Autonomy*, *Competence*, and *Relatedness* in a CURE will impact student motivation, which could in turn influence the willingness of students to engage and experience the critical components of a CURE (Figure 6-1). In this study, we explore: 1) how the motivation of students participating in CUREs varies by GTA; 2) how student motivation is impacted by student perceptions of their GTA's support for *Competence*, *Autonomy*, and *Relatedness* in the classroom; and 3) if student motivation relates to how students experience critical components of the CURE.

We hypothesize that students will perceive different levels of support from their GTAs with regard to *Autonomy, Competence*, and *Relatedness* in the CURE, and that students who perceive that their GTA does support these elements will be more autonomously motivated in the CURE. Finally, we hypothesize that students who are more motivated in the class will be better able to recognize and value the opportunities to practice critical CURE components.

Methods

Study Context

We conducted this study in Fall 2019 at a research-intensive institution in the Pacific Northwest, where students in a high-enrollment introductory biology course participate in the HHMI SEA-PHAGES CURE curriculum (Jordan et al., 2014) in 20 laboratory sections (n=440 students) taught by nine GTAs. We used a multiple-case study design, wherein we treated each of the nine GTA's pooled lab sections as a single "case," with two embedded units for analysis: 1) the GTA; and 2) their students (Yin, 2017). We found that GTAs differ in their perceptions of their role as a CURE instructor (Goodwin, Cary, et al., 2021), and students who are taught by different GTAs experience their lab environment and the essential elements of a CURE differently (Goodwin, Cary, Phan, et al., 2021 (in prep)). Here, we use interviews with students of each GTA to understand how the support provided by individual GTAs impacts students.

In the SEA-PHAGES curriculum, students collect soil samples from which they aim to isolate and characterize novel bacteriophages capable of infecting specific bacterial hosts. Through this curriculum, students experience each of the five CURE constructs: 1) they engage in multiple *Scientific Practices*, including learning different scientific techniques and processes such as data analysis and communication; 2) they *Collaborate* with other students and instructors on their projects; 3) they have opportunities to *Iterate* several of the experimental steps in order to successfully isolate and characterize their bacteriophages; 4) any bacteriophage they successfully isolate is likely to be *Novel* and previously undescribed by other scientists, due to the great diversity of bacteriophages; and 5) bacteriophages are archived in an online database and have the potential to be useful for other scientists (*Broader Relevance*). However, the *Broader Relevance* of this particular implementation of the SEA-PHAGES CURE is limited, as the bacterial host that students work with does not have a known relevance within the scientific community, and students in this course are unable to conduct genomic analyses that would increase the potential value of their contribution to the online database. Students who do not successfully isolate their own bacteriophage after attempting to do so for several weeks are given a sample of a previously isolated "practice" phage, and use this adopted practice phage to follow the same experimental steps throughout the remainder of the term as the students who do successfully find a novel phage.

Student Interviews

At the end of the term, we recruited students to participate in interviews to explore their perceptions of how their GTAs impacted their experiences in the CURE. Two researchers visited each lab section during the final weeks of class to announce the opportunity for student interviews and followed up with an email recruitment to all enrolled students. We received responses from 40 interested students, and from this pool we selectively scheduled interviews with students based on the lab section in which they were enrolled. In total, we conducted interviews over an online video-conferencing platform with 25 students, interviewing two to three participants from each of the nine GTAs who had taught the CURE that term. Interviews were conducted by a single researcher using a semi-structured format, allowing the researcher to ask follow-up questions as needed while following a pre-determined set of interview questions (Cohen & Crabtree, 2006). Interview questions were developed by two researchers, and questions were designed to explore student's perceptions of experiencing specific CURE elements in the course, perceptions of their overall experience in the CURE, and perceptions of how their GTA influenced their experiences in the classroom (for full interview protocol, see Appendix E.1). The interview protocol was piloted with six introductory biology students who had taken a CURE at a different institution, and student responses in pilot interviews subsequently prompted minor clarifying revisions to the final interview protocol.

Students were assured that their participation in the survey would not be disclosed to their GTA or instructor of record and would not affect their course grades. Self-reported demographic information for participants was collected via a class-wide end-of-term survey. Interview participants were offered $20 gift cards as compensation for their time, and this study was approved by the Portland State University Institutional Review Board (no. 196388-18).

Data Analysis

A team of four researchers read through a subset of interview transcripts (six transcripts) and formed a list of potential codes. While these codes were generated inductively from themes that appeared in the interviews, we set out with the intention of exploring: 1) student motivation in the CURE; 2) how student interactions with and perceptions of their GTA impacted their experience in the CURE; and 3) student perceptions of experiencing critical CURE components. We used these *a priori* ideas to reorganize our initial list of codes, grouping all codes into organized themes aligning with SDT (*Amotivation*, *Identified extrinsic* motivation, and *Intrinsic* motivation, as well as the basic needs of *Competency, Autonomy,* and *Relatedness*; Ryan & Deci, 2000)) and the CURE constructs (*Use of Scientific Tools and Practices, Iteration, Collaboration, Broader Relevance,* and *Novel Discovery*; Auchincloss et al., 2014). Because students often discuss *Broader Relevance* and *Novel Discovery* without making a clear distinction between the two concepts, we join previous researchers in collapsing these two themes into a single category, *"Relevant Discovery,"* for analysis (Cooper et al., 2019; Goodwin, Anokhin, et al., 2021). Each code within the CURE and SDT-related themes was characterized by a short title and a definition that was created to help the researchers understand and remember the scope of the idea captured by each code. Researchers used this draft codebook to code three additional interview transcripts and met after reading each transcript to discuss coding decisions and to edit and refine the codebook.

We then used the final codebook to code all student interviews, including the nine interviews used in codebook development. Each researcher read the same interview, and then met as a team to discuss every coding decision to consensus. Informed by the SDT-aligned coding, we additionally considered each interview holistically and categorized students by their overall motivation level with regard to engaging in the CURE: "highly motivated" students were enthusiastic and had high internalized value for the CURE, and often went above and beyond what was strictly required of them in the CURE. "Somewhat motivated" students often expressed varied levels of interest in engaging in the CURE, and had mixed perceptions of the value of the CURE. While "somewhat motivated" students did not strongly dislike the CURE, they rarely reported engaging in the class beyond what was required of them. "Amotivated" students perceived very little value in the CURE and had little to no interest in doing more than what was required of them to get their desired grade in the course.

We conducted a quality-check of our coding assignments by dividing all transcripts among researchers to individually reread each interview and flagged any sections where they questioned the coding assignment. Finally, we met to discuss flagged coding assignments, with very few changes made to the previous coding decisions.

Researcher Expertise and Reflexivity

All researchers were unaffiliated with the study institution, but the background of the researchers and work done through additional components of this case study provided researchers with a deep understanding of the study context. The researcher (ECG) who conducted the interviews and led analysis of the interviews had participated in the SEA-PHAGES curriculum as a student, had several years of experience as a teaching assistant of the SEA-PHAGES curriculum at a different institution, and also had experience designing and teaching independent CUREs outside of the SEA-PHAGES curriculum. Undergraduate and postbaccalaureate researchers (JRC, VDP, and HT) assisted in interview coding, and offered their collectively diverse perspectives as first- and continuing-generation, and traditional- and nontraditionally-aged students. Senior researcher (EES) has extensive experience in developing CUREs and in conducting research on CURE instruction. As the work presented here is part of a larger case study, researchers had deep familiarity with the context of the CURE that interview participants had participated in: one researcher (ECG) conducted teaching observations of every GTA during one week of the CURE, taking notes on GTA behavior and how each GTA facilitated critical research elements. Interviews were also conducted with each GTA to learn about their perspectives in facilitating a CURE. Two researchers (ECG and EES) conducted in-class modified focus groups with each lab section in the course, developing rapport through whole-class conversations with the students about their experiences in the CURE. As we conducted interviews with students at the end of the term, participants therefore had some familiarity with the researchers and with the goals of the study. We used information from our experiences with SEA-PHAGES and our findings from observations, GTA interviews, and student focus groups to inform and provide validity evidence for our decisions and interpretations throughout our interview analysis in the present study.

Results

Participant information

We interviewed 25 students, representing each of the nine GTA's sections at least twice. The average participant age was 19.9 years old (SD = ± 1.5 years), and 24 participants self-identified as female. Our high proportion of female interview participants likely reflects both the demographics of the broader course (approximately 70% of enrolled students self-identified as female), and volunteer-bias, such that women are often more likely to volunteer than men (Rosenthal et al., 1975). We recognize this as a limitation in our work. Nine participants self-identified as belonging to a racial or ethnic group historically underrepresented in STEM fields, and eight participants identified as first-generation college students. Only one participant reported having previously participated in an apprentice-based research experience.

To help distinguish between the different GTAs who taught the students interviewed in this study, we assigned sea-themed pseudonyms to each GTA, as a nod to the SEA-PHAGES curriculum (see Figure 6-2 for pseudonyms).

Students vary greatly in their motivation for the CURE, even when taught by the same GTA

Throughout their interviews, students frequently made statements that revealed factors and perceptions that contributed to their motivation (or lack thereof) with regard to buying-in to the CURE. Codes within the *Amotivation* theme described students who lacked value for the CURE or made it clear that their motivation to participate was strictly externally regulated (i.e., compliance with course expectations to achieve a certain grade). These codes included “Student did not enjoy course” (coded for 6 out of 25 students), “Student had no interest in doing more than minimum course requirements” (5 students), and “CURE is not executed effectively to benefit students” (9 students, Table 6-1). The second theme, *Identified extrinsic motivation*, describes codes where students recognized the utility value of participating in the CURE, including codes such as “Experience was generally beneficial for students” (13 students), “CURE was relevant for the student’s professional future” (9 students), “CUREs provide career clarification” (11 students), and “CURE makes research more accessible to students” (10 students, Table 6-1). Finally, the theme *Intrinsic motivation* included codes such as “CURE project made the lab meaningful” (14 students), “Student found the course enjoyable or interesting” (19 students), and “Student experienced project ownership” (9 students, Table 6-1).

Guided by our motivation codes, we holistically assessed the overall motivation of each interview participant with regard to their autonomous drive to engage in the CURE. “Highly motivated” students (n=10) made statements throughout their interview that demonstrated clear *Intrinsic* and *Identified extrinsic* motivation for the CURE. “Amotivated” students (n=6) demonstrated very little *Intrinsic* motivation for the CURE, and frequently made statements that indicated they lacked value for the CURE and did the minimum to comply with expectations of the course. “Somewhat motivated” students (n=9) fell between these two ends of the spectrum. Although we only interviewed two or three students of each GTA, we considered the holistic motivation of each student taught by different GTAs to assess if there could be a connection between instructor and student motivation. The two or three student representatives of each GTA often varied in their holistic motivation for the CURE, implying that individual GTA’s are not solely responsible for their student’s motivation—students of the same GTA likely vary in their overall motivation to engage in the CURE (Figure 6-2).

Despite the variability of student motivation even when taught by the same GTA, students who experienced less motivation for the CURE often directly indicated that their GTA was the single factor preventing them from experiencing higher levels of intrinsic interest and motivation in the lab. For example, two of Orca’s three students said they thought they would have really enjoyed the CURE if they had a positive and more supportive GTA. Two additional students—a "somewhat motivated" student and an "amotivated" student taught by GTAs Wave and Urchin (pseudonyms), respectively, described separate incidents where the PhD-level lab coordinator was called on to substitute in their classes for their GTAs. Both students indicated that the lab coordinator conveyed far more excitement and clarity about the purpose of their experiments, and felt that if their regular GTA instructor had been similarly encouraging and informative, they would have had a more enjoyable and beneficial experience in the class:

> *"The first thing that I want to do when I'm a teacher is make kids feel welcome and excited to be here, and then learning can come… It was really frustrating for me to see the lack of commitment and professionalism and passion [our GTA] put into teaching. And that definitely contributed to my overall experience of the lab…. But again, the idea of [the CURE], I liked a lot. I think if I had a different TA, I would have loved the lab." —Somewhat motivated student, GTA: Wave*

These students were acutely aware that their GTA's lack of support of their experiences in the classroom prevented students from fully understanding and benefitting from the CURE.

Highly motivated students are more likely to experience Competence and Autonomy, and to perceive that their GTAs support Competence, Autonomy, and Relatedness

We coded student perceptions as they related to experiencing *Competence*, *Autonomy*, and *Relatedness* in the CURE (Table 6-2). Student experiences of *Competence* (or lack thereof) often related to their understanding of the overall purpose of the class and the purpose of their daily lab experiments, their perceptions that the course was appropriately challenging for an introductory biology lab class, and their perception of gaining competence in lab skills or scientific processes throughout the course. Their GTA supported their *Competence* by discussing the purpose of the CURE and helping to contextualize their daily lab procedures, facilitating collaboration and iteration, and generally providing effective teaching and clear communication. Students who perceived that their GTAs did not support *Competence* often described that their GTA failed to effectively provide these elements (Table 6-2).

Realistically, students had more or less the same amount of control and *Autonomy* in the course: they were able to choose where to collect their soil samples and how many samples to collect, as well as make choices related to troubleshooting and minor deviations from experimental protocols, and potentially name their phage if they were successfully able to isolate one. However, some students perceived they had relative control and *Autonomy* within the class, often because they perceived independent responsibility and felt like the experimental decisions they were able to make were meaningful. Other students felt constrained by the structure of the course, and felt they lacked individual *Autonomy* because of the limited importance of the few decisions they were able to make (Table 6-2). GTAs who supported *Autonomy* encouraged students to make independent decisions in their class, emphasized the impact of the areas of the experiments where students experienced control, and facilitated independent work and troubleshooting by “guiding” rather than “telling” students what to do in the class. On the other hand, GTAs who did not support *Autonomy* tended to overexert their own control over student’s experiments, by telling students exactly what to do and how to do it, and occasionally even intervening in student’s experiments themselves, rather than letting their students carry out the lab techniques independently (Table 6-2).

Instances of students experiencing *Relatedness*—a sense of community and comfort, both with their classmates and with their GTA—were closely tied with their perceptions that their GTA supported (or failed to support) *Relatedness*. Students perceived that their GTA's supported *Relatedness* in the class when GTAs made themselves available and approachable to students, demonstrated their own investment in the course, put effort into making the course exciting and engaging, and were receptive to diverse student needs (Table 6-2). These actions both supported students' connection with their GTA, and their sense of comfort, morale, and community within the class. Students who felt their GTAs did not support *Relatedness* reported that their GTA sometimes seemed distant or unapproachable, did not always have a positive attitude, and did not seem invested in the course or their students (Table 6-2).

Discussions of the GTAs' support for *Competency, Autonomy*, and *Relatedness* came up frequently in student interviews. As a proxy to gauge the degree to which students found their GTA supportive or unsupportive of *Competency*, *Autonomy*, and *Relatedness*, we considered the number of times these codes were used in analyzing students' interviews, both by student motivation group and at the level of the individual student (Figure 6-3). "Highly motivated" students more frequently described instances of their GTA supporting their *Competency* than did "somewhat motivated" and "amotivated" students—who were more likely to describe that their GTA did not support their competence (Figure 6-3, Panels A and B). All of the "highly motivated" students described several times throughout their interviews that their GTA supported *Relatedness*, while "amotivated" students were instead more likely to describe at least one instance where their

GTA did not support *Relatedness* (Figure 6-3, Panels C and D). Although experiences related to *Autonomy* came up less frequently overall in the interviews, a similar pattern was observed: "highly motivated" students were more likely to acknowledge that their GTA supported their autonomy, while "amotivated" students more frequently described that their GTA did not support *Autonomy* (Figure 6-3, Panels E and F).

Student motivation is associated with perceptions of experiencing critical CURE components

Throughout the interviews, we asked each student about their perceptions of experiencing the critical CURE elements of *Scientific Practices*, *Collaboration, Iteration,* and *Relevant Discovery*. Most students reported using multiple scientific tools and practices throughout the term (22 of 25 students), experiencing sufficient collaboration (18 students), and experiencing sufficient iteration (18 students, Table 6-3). The remainder of the students felt that their experiences of using scientific tools and practices, as well as experiencing collaboration and iteration, were limited and insufficient within the course. In contrast, only ten students believed that their CURE project had definite potential for relevant discovery, with an additional eight who acknowledged that relevant discovery within their project was perhaps present but very limited. Seven students—over a quarter of our interview participants—felt that the project lacked any potential for relevant discovery at all (Table 6-3).

To explore how perceptions of these elements relate to student motivation, we compared the number of students in each motivation group who reported experiencing each element (Figure 6-4). The same pattern was observed for each CURE element: as motivation level decreased, from the "highly motivated" to the "somewhat motivated" and finally the "amotivated" group, the proportion of each student group who reported that the CURE was deficient in a critical element increased (Figure 6-4). This pattern was especially striking for the element of *Relevant Discovery*: while only three of the ten "highly motivated" students perceived that the potential for *Relevant Discovery* was limited or absent from their course, all six of the "amotivated students" reported that the course had limited to no potential for *Relevant Discovery* (Figure 6-3).

In addition to asking students about their perceived potential for *Relevant Discovery* in their class, we asked students how the "outcome" of their CURE projects (i.e., whether they experienced *Discovery* by successfully finding and isolating their own phage, or instead had to adopt a "practice" phage after failing to isolate their own phage) impacted their feelings about the course. Eleven students reported that failing to find their own phage and instead adopting a practice phage decreased their *Intrinsic* motivation in the course—these students were less interested or excited to engage in the course, often because they felt less ownership or knew that they no longer had the potential to make a relevant scientific contribution (Table 6-4). On the other hand, nine students described that their experience of successfully finding their own phage increased their *Intrinsic* motivation—often dramatically improving their overall experience in the course, by increasing their perceptions of relevance and ownership (Table 6-4). Only two students felt that their *Intrinsic* motivation for the CURE was not impacted by finding—or failing to find—a phage (Table 6-4). While subsets of students in the "highly motivated," "somewhat motivated," and "amotivated" groups all reported that adopting a phage decreased their intrinsic motivation, and finding a phage increased their intrinsic motivation, students in the "highly motivated" group were much more likely to report that finding a phage increased their intrinsic motivation for the course (Figure 6-5).

It is critical to note that motivation often impacted the actual experiences of students in the course, rather than their just their perceptions of the course. For example, while all students had opportunities to collect extra soil samples and both stay longer in-class during scheduled class time or to come in during open lab hours to repeat experiments, it was often the "highly motivated" students who described taking advantage of these opportunities. These students were the most invested in the course and willing to put effort in beyond the minimum required to get a satisfactory grade. Consequentially, they often engaged in more *Iteration* than other students, and subsequently also had a much higher likelihood of successfully discovering and isolating a novel phage—as illustrated in the quote below:

> *"We would mess up [our experiments], so it was a trial and error for every single lab. But we didn't ever really feel bad, we never got discouraged, because our TA was very encouraging. Every time I messed up, they're like, "It's okay. Just start over…" My partner and I chose to repeat [certain experiments] just in case something went wrong... We were down to the wire about finding [a phage] or else we would have to adopt [the practice phage] and we really didn't want to adopt one. At one point we were running like seven samples at one time." —Highly motivated student, GTA: Shell*

While high motivation and subsequent increased iteration often led to students successfully isolating a phage, other students reported that finding a phage early in the course (without putting much effort in) also boosted their intrinsic enjoyment of the course, though that initial excitement was not necessarily enough to keep students excited and engaged throughout the course:

> *"I would have not enjoyed the class that much [if I did not find a phage]. There was a little bit of satisfaction in finding a phage the first week. It was like "Yeah, we did it!" Because our TA was very much, "I don't think anyone's going to find phage," because [Sand] had bad experiences in the past with students not finding phage. And then our group found one the first week, so kind of exciting. But as the weeks progressed, our phage got weaker or something, and the lab got harder. I kind of accepted that, but I think that if I didn't find a phage, it probably would have been not an enjoyable experience overall." —Amotivated student, GTA: Sand*

As demonstrated in both of the quotes above, the manner in which GTAs framed and supported the elements of *Iteration* and *Relevant Discovery* impacted students' perceptions of and motivation to engage in these critical experiences of the CURE.

Discussion

Student experiences in GTA-taught courses are impacted by a multitude of complex factors, including student variables (knowledge, retention, and interest), GTA variables (attitudes, beliefs, and pedagogical actions), and the contextual variables specific to the institution and course (Reeves et al., 2016). It is likely that some students will experience high or low motivation for a course regardless of their GTA—this is supported by our finding that students of the same GTA could experience vastly different levels of autonomous motivation (Figure 6-2), indicating that there are GTA-independent variables that influence student motivation. However, our interviews demonstrate that for certain students, the influence of individual GTAs could "make-or-break" their students' enjoyment of their experience and autonomous motivation to engage in the CURE.

Unsupportive GTAs may prevent students from experiencing high autonomous motivation

As expected, our results align with the SDT framework outlined in Figure 6-1: students who reported experiencing more *Competence*, *Autonomy*, and *Relatedness*—and who perceive that their GTA's support these elements in the classroom—were more autonomously motivated to engage in the CURE (Figure 6-3). These findings align with previous work showing that instructors who provide strong social support for their students (i.e., *Relatedness*) positively impact their students' motivation, as well as other affective learning outcomes (Baker & Goodboy, 2018; Cornelius-White, 2007; Seidel & Tanner, 2013; Wubbels & Brekelmans, 2005). While "somewhat motivated" and "amotivated" students often still described instances where they recognized that their GTA supported their *Competence*, *Autonomy*, or *Relatedness*, these students were more likely than "highly motivated students" to describe instances of their GTA failing to support their *Competence, Autonomy,* or *Relatedness* (Figure 6-3). We propose that GTAs may serve as "gatekeepers" for students to experience high autonomous motivation in a CURE, in that if students perceive that their GTA is actively unsupportive of these elements, it may bar students from experiencing high autonomous motivation in a CURE. Indeed, several "somewhat motivated" and "amotivated" students specifically indicated that the lack of support from their GTA was the largest barrier to having a more enjoyable or beneficial experience in the lab.

Failing to provide support for student's *Autonomy, Competence*, and *Relatedness* not only prevents students from fully enjoying or engaging in the CURE, but may be actively detrimental to student success. For example, a study of 897 introductory biology students taught by six different instructors found a correlation between higher self-reported anxiety and lower student ratings of their instructor's support in the classroom. Students in this study often justified their instructor's support (or lack thereof) with explanations the authors refer to as "relational" and "pedagogical" support—these themes closely align with the concepts of *Relatedness* and *Competency* (Schussler et al., 2021). Instructors who fail to provide these supports may even induce a biological stress response in their students: a study of undergraduates conducting a puzzle-solving activity under the guidance of autonomy-supporting or unsupportive (i.e. "controlling") teachers revealed that students with autonomy-supportive instructors had decreased cortisol levels, while students with controlling teachers had elevated cortisol levels, as one would expect to experience in high-stress environments (Reeve & Tseng, 2011). Regardless of instructor type (i.e., GTA or faculty) and context (CURE or otherwise), instructors who fail to support these elements are likely creating more stressful learning environments for their students.

It is possible that the combination of the increased complexity of a CURE and the fact that GTAs are often novice researchers and teachers result in an instructional context where GTA instructors are less prepared to provide these supports for their students—future studies could directly explore this possibility. Regardless, our findings demonstrate that some GTAs of CUREs are failing to support their student's *Autonomy, Competence,* and *Relatedness,* and thereby likely preventing some students from experiencing higher levels of autonomous motivation to engage in the CURE—an outcome likely to result in less effort, engagement, and lower affective and academic outcomes for their students (Howard et al., 2021).

Student motivation may determine the extent to which students perceive and experience essential CURE elements

We found that "highly motivated" students in the CURE are more likely to both engage in critical CURE elements and perceive that these elements were sufficiently present in the course (Figure 6-4). We hypothesize that these "highly motivated" students are consequentially more likely to benefit from participating in a CURE, because they engage the most with the research elements that a CURE is designed to provide (Auchincloss et al., 2014). On the other hand, "somewhat" and "amotivated" students, who are less likely to perceive and experience the essential elements of a CURE, may not be truly engaged in the CURE as intended, and therefore may not reap the same benefits of participating in a research experience. In offering CUREs, we may therefore only be providing "research experience" to a fraction of the students in the class—the students who are already motivated and receptive to engaging in such an experience, and the students whose motivation to engage in the experience can be fostered by a supportive instructor.

Could unsupportive GTAs perpetuate inequities in which groups of students benefit from participating in a CURE?

Guided by our data, we propose a model wherein GTAs act as "gatekeepers" for some students in developing high autonomous motivation in a CURE, and in doing so additionally impact student's probability of perceiving that they have experienced the elements essential to a CURE (Figure 6-6). Further, students who enter the course with high scientific cultural capital may experience high motivation and benefit from the CURE regardless of the influences of their GTA, because such students may already have high

Identified Extrinsic motivation and appreciation of the potential benefits of participating in research experiences (Figure 6-6).

Previous research has found that perceiving one's instructor as supportive is particularly impactful in increasing motivation for students who begin the class with low initial autonomous motivation (Black & Deci, 2000). Therefore, while unsupportive GTAs likely create unpleasant experiences for all students, these GTAs may be particularly detrimental for students who begin the semester with lower autonomous motivation. First-generation college students and students from nondominant groups often have lower scientific self-efficacy and awareness of the potential value of scientific research experiences than their represented peers—factors that contribute to lower autonomous motivation (Bangera & Brownell, 2014; Hernandez et al., 2013; Jacobs, 2005). This pattern could be explained by the model of community cultural wealth: traditional scientific and educational systems were designed to align with the cultural capital developed in students of privileged, dominant groups, and these systems fail to leverage the cultural knowledge of students from nondominant groups (Yosso, 2005). First-generation students and students from nondominant groups therefore may need specific supports to succeed and persist in STEM fields. Quality mentorship has already been identified as an important factor in developing the scientific self-efficacy, identity, and values for underrepresented students participating in apprentice-based research experiences (Estrada et al., 2018). It is therefore likely that high-quality support from science instructors (including GTAs), will play a pivotal role in providing an equitable and supported experience for first-generation and underrepresented students. Conversely, being taught by an unsupportive instructor could stunt the development of *Identified Extrinsic* and *Intrinsic* motivation for the CURE, resulting in students failing to autonomously engage and fully benefit from a CURE experience (Figure 6-6).

Antithetical to the ideal CURE scenario, limited perceptions of Relevant Discovery and experiences of "Failure" dampened student's intrinsic motivation

Emerging research suggests that experiencing failure in the context of participating in a CURE can provide a meaningful, productive, and motivating experience (Gin et al., 2018; Goodwin, Anokhin, et al., 2021). However, students in this study reported that the outcome of their experiments—either finding or failing to find a phage—had significant impacts on their intrinsic motivation towards the course, such that a majority of students failed to successfully isolate their own novel phage, and reported that this failure negatively impacted their intrinsic motivation (Figure 6-5). Previous work has found that experiences of failure in a CURE are particularly powerful in the context of *Relevant Discovery*: because students are attempting to address a novel and relevant research question, students perceive failing to answer that question as a legitimate scientific outcome, while failing in the more structured contexts of traditional laboratory courses may simply feel academically defeating (Goodwin, Anokhin, et al., 2021). However, students in the current study perceived that *Relevant Discovery* was the most limited or absent CURE element in their course (Figure 6-4). *Relevant Discovery* is the element that most distinguishes a CURE from traditional and inquiry-style laboratory courses, in which students may still have opportunities to experience scientific practices, collaboration, and iteration (Auchincloss et al., 2014; Cooper et al., 2019; Goodwin, Anokhin, et al., 2021).

Therefore, in a scenario where students perceive that the *Relevant Discovery* of their CURE is very limited, students may be interpreting an experience of failure more as they would in a traditional laboratory course. “Somewhat motivated” and “Amotivated students were the most likely to fail to perceive *Relevant Discovery* (Figure 6-4, Panel D) and to report that their intrinsic motivation was negatively impacted by their ultimate failure to find a phage (Figure 6-5), providing further evidence that students with lower autonomous motivation are less likely to experience the critical CURE element of *Relevant Discovery* (Figure 6-6).

As education researchers, we concur with a number of the student’s assessments that that *Relevant Discovery* in this CURE is limited—perhaps to the point of being absent, since the contribution to a large online database of a single isolated phage, with no known medical or scientific relevance, and without accompanying genomic information, is indeed a small contribution. This limitation will likely garner less buy-in from students than a CURE with a more obvious broader impact. There is wide variation in implementation of the SEA-PHAGES curriculum—the full implementation of this curriculum spans two terms and includes bioinformatic analyses, and some students may have the opportunity to present their work at an annual SEA-PHAGES research symposium, at regional and national meetings, and occasionally through peer-reviewed publications (Jordan et al., 2014). However, many institutions do not have the funding or the logistical capacity to provide this full experience for students, and may therefore engage students in smaller parts of the overall curriculum, as is feasible. There is evidence of positive student outcomes from participating both in the full SEA-PHAGES curriculum (Hanauer et al., 2017; Jordan et al., 2014), and in modified one-semester versions where students only participate in the phage discovery portion of the course (Staub et al., 2016), as in our study. Limited or absent presence of the element of *Relevant Discovery* is perhaps a potential vulnerability of the SEA-PHAGES curriculum, and the extent to which this element exists across the various contexts in which the SEA-PHAGES curriculum is used should be further explored. If *Relevant Discovery* is insufficiently integrated into the curriculum, we may be offering students an experience more similar to an advanced inquiry course rather than a CURE (Auchincloss et al., 2014; Goodwin, Anokhin, et al., 2021). Regardless of the classification of this curriculum as an inquiry or a CURE, it is clear that there are positive outcomes for numerous students who experience the SEA-PHAGES curriculum, and researchers and educators should continue the ongoing discussions regarding the merits of both of these experiences for students (Cooper et al., 2019; Goodwin, Anokhin, et al., 2021).

Limitations

We conducted this study to understand the impacts that different GTAs could have on their students in the single context of the SEA-PHAGES CURE curriculum in an introductory biology course at a large research institution in the Pacific Northwest. We anticipate that different CURE contexts would result in very different dynamics between students and their GTAs: for example, initial student motivation is likely to be different in upper-division courses that students opt into rather than a required introductory biology lab. Further, universities that integrate independent CUREs rather than network CUREs may find it easier to establish the "broader relevance" of their courses, as the research questions in independent CUREs often align with a faculty member's research (Shortlidge et al., 2017). In these cases, GTA instructors may be conducting graduate research that aligns with the CURE they are teaching, and the added familiarity GTAs would likely have with the research background may make it easier to support students in the CURE. Further work could explore the efficacy and capability of GTAs to support their students in these additional CURE contexts.

As a qualitative study with 25 student participants, we do not expect that we have fully represented the experiences of all students even within our single CURE study context. Although we selectively recruited participants who had been taught by all nine GTAs teaching the course, and we found our participants ranged widely in their motivation and experiences within the CURE, influences due to volunteer bias could still skew our study population and perspectives represented in our study (Rosenthal et al., 1975). For example, though female-identifying students made up approximately 70% of the course population, they were unexpectedly overrepresented in our study sample, where 96% of students self-identified as female.

Conclusions

Our qualitative study serves as an example of the potential variation in how student perceptions of the support provided by their GTA can impact their autonomous motivation, and provides a potential model for how GTA support may impact student experiences of essential CURE elements. Faculty implementing GTA-taught CUREs should be aware of the potential variation in support students of different GTAs may receive, and be conscientious of the possibility that CUREs taught by GTAs who fail to offer sufficient support to their students may unsuccessfully engage students in the elements of a CURE, which could be particularly detrimental students who enter the class with lower levels of motivation to engage in research. Educators implementing the SEA-PHAGES CURE in particular would benefit from considering how the element of *Relevant Discovery* is presented in their course, and consider opportunities to further develop this aspect of the CURE for their students. For example, instructors could perhaps partner with microbiologists or bacteriophage researchers at their institution to align their implementation of the SEA-PHAGES curriculum with the goals of a local faculty member's research program, or find other ways for students to interact with scientists conducting bacteriophage research.

Our research builds on the vast body of work addressing the importance of supporting the elements of *Competence, Autonomy*, and *Relatedness* in efforts to foster student motivation. Future research should continue to explore the impacts of GTA support on student outcomes in CUREs, and consider how to provide assistance and training for GTAs of CUREs to develop GTA capacity to best support their students. Here, we have demonstrated that student experiences in CUREs likely can be largely influenced by their GTA, but this work does not identify overall trends that individual GTAs may have on their students at the scale of the entire class. Future work should explore this potential variability in student outcomes for students taught by different GTAs, and consider individual instructors as potential variables in influencing student outcomes in a CURE.

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Figures and Tables

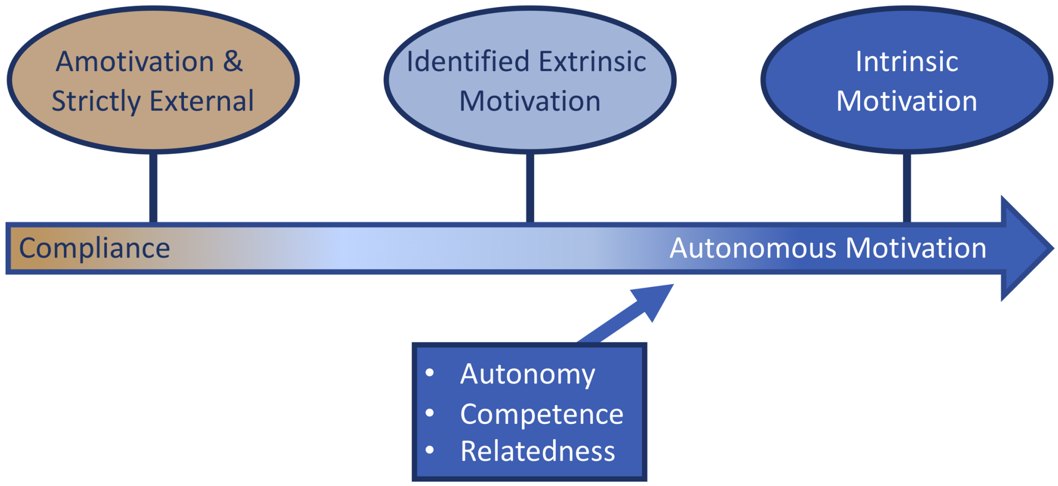

Figure 6-1. *Autonomy, Competence, and Relatedness are hypothesized to support autonomous forms of motivation*

We hypothesize that students who perceive higher levels of Autonomy, Competence, and Relatedness are likely to experience more Identified extrinsic and Intrinsic motivation, and are therefore more likely to engage in the CURE. Students who experience insufficient Autonomy, Competence, and Relatedness are unlikely to be motivated to engage in the CURE beyond complying with minimum course requirements (Amotivation/Strictly External motivation). Figure inspired by Ryan & Deci, 2000.

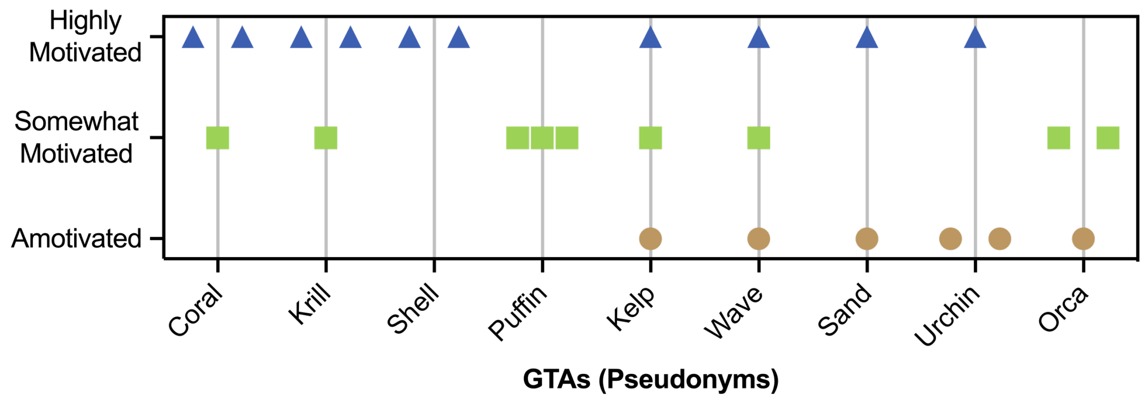

Figure 6-2. *Students' holistic motivation by GTA*

Icons represent the number of "highly motivated" (blue triangles), "somewhat motivated" (green squares), and "amotivated" (brown circles) students of each GTA.

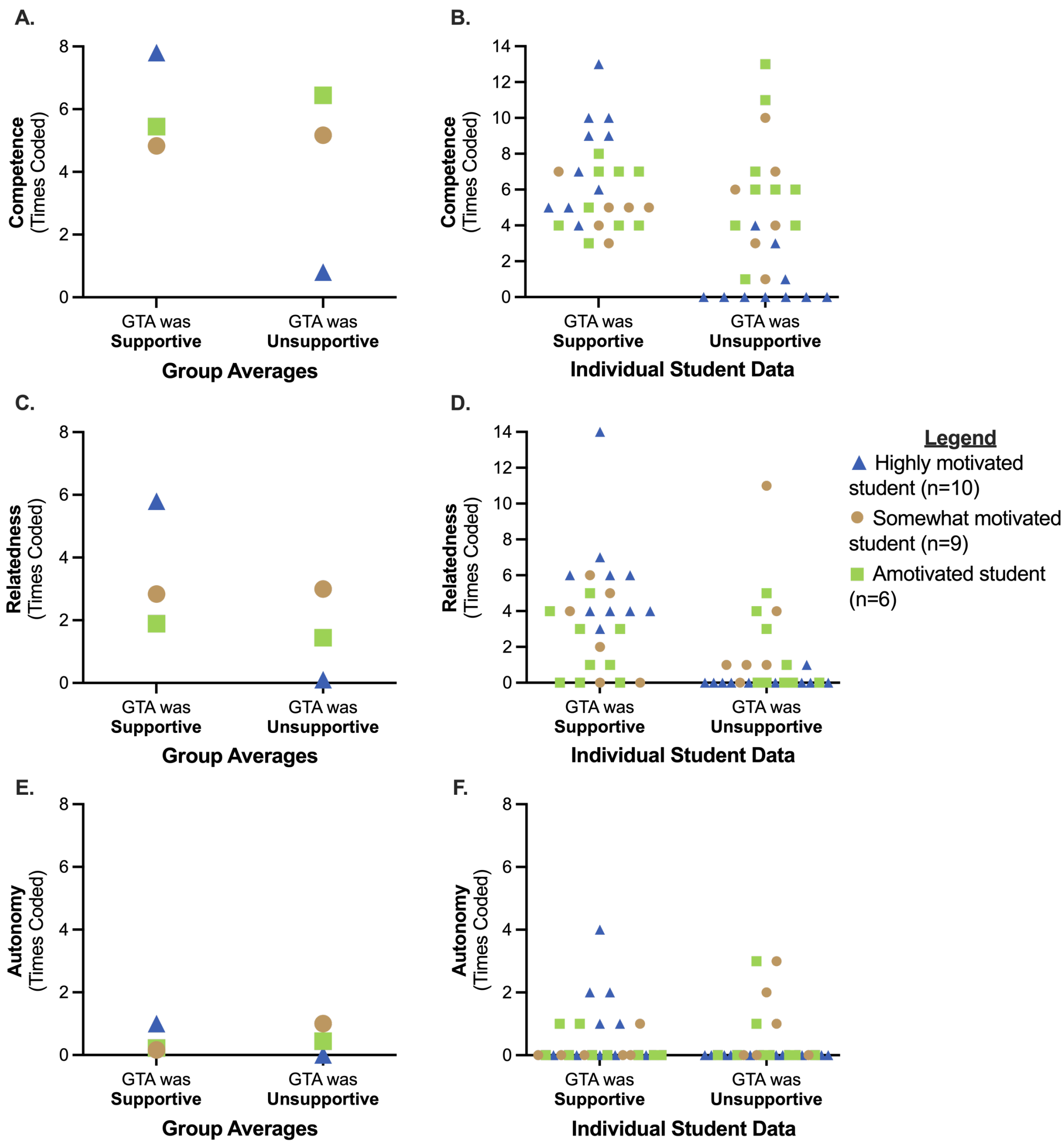

Figure 6-3*. Student motivation level is related to experiences of SDT basic needs*

Icons indicate "highly motivated" (blue triangles, n=10), "somewhat motivated" (green squares, n=9), and "amotivated" (brown circles, n=6) students. Icons in panels A, C, and E represent the average number of times, for students within each motivation group, that researchers coded that the GTA was either supportive or unsupportive of Competency (Panel A), Relatedness *(Panel C) and* Autonomy *(Panel E). In Panels B, D, and F, each icon indicates the number of times each theme was coded within a single students' interview. Because* Autonomy *was less frequently discussed in interviews, the y-axis in Panel F represents a smaller range, compared to panels B and D. "Highly motivated" students more frequently discuss their GTAs' support for student Competence, Relatedness, and Autonomy, while "somewhat motivated" and "amotivated" students more frequently discuss their GTAs' lack of support.*

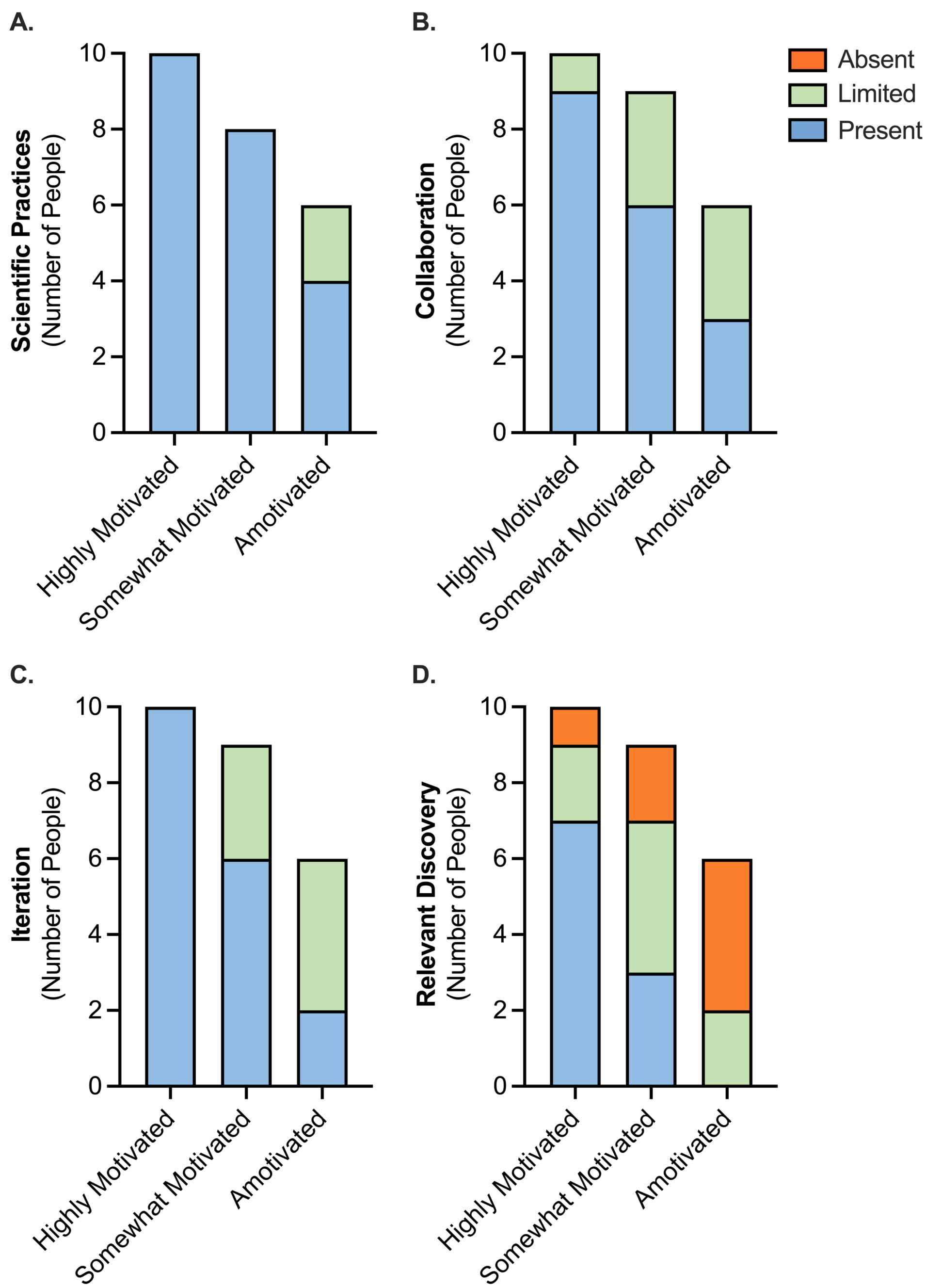

Figure 6-4. *Student motivation is related to perceptions of experiencing critical CURE components*

As compared to both somewhat motivated (n=9) and amotivated (n=6) students, highly motivated students (n=10) appear more likely to recognize that they used multiple Scientific Practices (Panel A), experienced sufficient Collaboration (Panel B), experienced sufficient Iteration (Panel C), and that their project had potential for Relevant Discovery (Panel D).

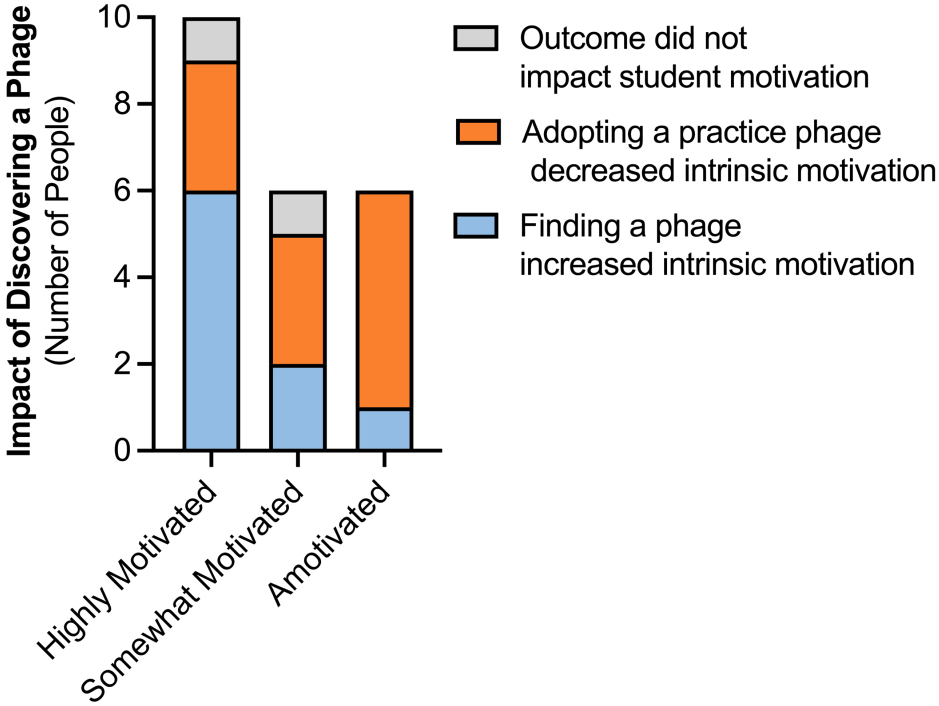

Figure 6-5. *Discovering a novel phage may be related to student motivation*

"Highly motivated" students (n=10) were more likely than "somewhat motivated" (n=6) or "amotivated" students (n=6) to report that successfully finding a novel bacteriophage of their own (rather than adopting a stock phage to use while completing the term's activities) increased their intrinsic motivation in the CURE. Note that while there were nine "somewhat motivated" students in our study, three did not clearly express if the outcome of their projects impacted their motivation.

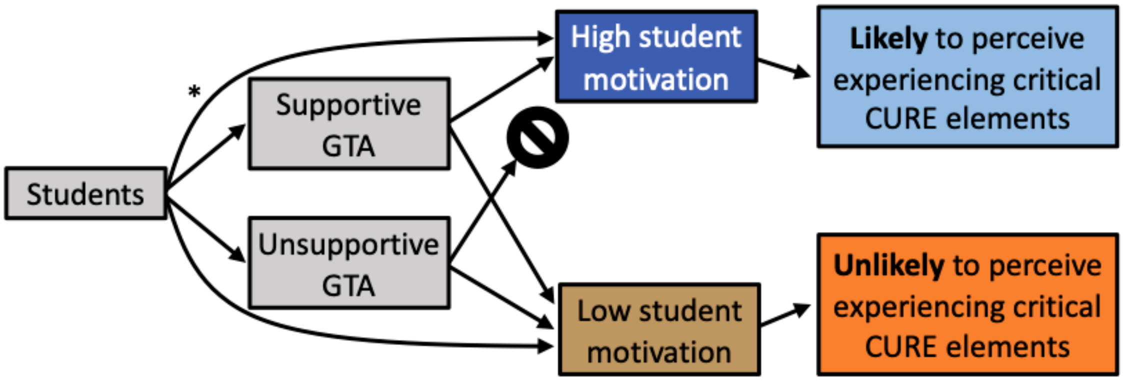

Figure 6-6. *Proposed model of GTA-mediated experiences for students in a CURE*

*A student's autonomous motivation to engage in a CURE may be independent of their GTA, especially for students who begin the class with higher scientific capital, who are then likely to be highly motivated in the CURE (represented by path *). For other students, GTAs serve as "gatekeepers" to developing autonomous motivation: while students who perceive that their GTA is supportive may or may not consequently experience high autonomous motivation in the CURE, students who perceive their GTA is unsupportive are unlikely to experience high autonomous motivation. Students who ultimately experience low autonomous motivation in the class are unlikely to recognize they have experienced critical CURE elements.*

Table 6-1. *Themes related to student motivation to engage and invest in participating in the CURE*

Motivation-Related Themes	Example Student Quote*
Amotivation: Student is not motivated to engage in the CURE, doesn't see value in participating or learning from the research experience due to not enjoying course or the CURE not being executed effectively.	*"I absolutely dread going to lab. I used to like biology, and I was on the microbiology track… [In lab] I'm bored out of my mind, and I'm usually frustrated because the GTA has an 'interesting' way of explaining protocols. Usually, we're all frustrated and confused as to what we're supposed to be doing. When I have a purpose in mind, or I know why we're doing something, I enjoy it way more. I think that [purpose] would have contributed to my overall experience, if I actually had [understood the purpose]."*
Identified extrinsic motivation: Student values the utility of potential skills that can be gained from participating in the CURE; values relevance to their or other students' future careers/goals.	*"Undergraduates are encouraged to participate in research, and I'm personally trying to get into [a lab] myself. So now to be able to confidently say that I can function in the lab environment is important. Just having the [research] experience in the first place [was valuable], so you're not going into a research lab and you've never seen or used a micropipette before."*
Intrinsic motivation*:* Student is motivated to participate in the CURE because student found the course content or experience interesting, saw meaning in their CURE project, felt project ownership or greater appreciation for the experience.	*"I love going to lab, honestly. It's definitely one of the high points in my week just because I know that I get to go in and experiment with something all hands-on. It's very satisfactory, coming out of the lab knowing that I've made progress with the research that we're doing."*

* Quotes have been lightly edited for grammar and concision.

Table 6-2. *Themes related to students' perceived Competence, Autonomy, and Relatedness in the CURE and the support or lack thereof from their GTA*

Basic Needs Themes	**Example Student Quote***
COMPETENCE	
Student experiences *Competence*: The student perceives that they developed scientific knowledge or skills, or they developed understanding of the purpose of what they were doing.	*"I enjoyed coming to class and knowing exactly what I was going to do because I had done it for weeks in the past and I was able to do it more efficiently. Every time I got more comfortable with the procedure it made me understand [more]: when I first started, I didn't know exactly what we were doing. But as we repeated the project, we were able to understand." –Somewhat motivated student, GTA: Puffin*
Student experiences lack of *Competence*: The student perceives that they did not gain sufficient scientific knowledge or skills, or that they did not understand the purpose of their experiments or the overall project.	*"I was very confused until the very end [of the term], when I was writing the lab report and I was able to put everything together. Then I saw why each part was necessary. But going into lab each day, I was very confused as to why we were doing each step." –Highly motivated student, GTA: Krill*
GTA supports *Competence*: Student perceives their GTA to be an effective teacher and describes how they helped the student gain more proficiency in the lab.	*"If there was ever anything that [our GTA] wasn't sure about, they took the time to look it up… They found videos for us to watch, and articles, and stuff like that if we were confused about bacteriophage and what went on [in the CURE]. That was really helpful… I don't think [our GTA] had to go find those resources for us. It was cool that they took the time to do that, as opposed to other TAs: if they don't understand something, they're like, "Well, whatever. You have to figure it out, and I don't." –Highly motivated student, GTA: Coral*
GTA does not support *Competence*: Student perceives their GTA was an ineffective teacher, and describes how they neglected to help the student gain more proficiency in the lab.	*"Our GTA was very nice, but never seemed to listen to us. They just wanted to explain it [their way], and if we didn't understand, it wasn't really their issue. It was hard for us to figure out what we were supposed to be doing, because they would tell us one thing, and we would start doing that, and then they would tell us another thing. It was very confusing at times." –Somewhat motivated student, GTA: Orca*
AUTONOMY	
Student experienced sufficient *Autonomy*: Student perceived experiencing control over experiments and outcomes/decisions.	*"[It] felt like my own research experiment; everyone was doing the same thing, but it was still very different, and we were all getting different results. We collected different soil samples, which made it feel like our experiments were different. I had control over it, especially with [our experimental progress], because we could be on step two while someone else is on step five, and that's okay." – Somewhat motivated student, GTA: Wave*

Student lacked *Autonomy*: Student felt they lacked control and independence in their experiments.	*"No, [we did not have autonomy] because we have to do [specific] experiments and we're supposed to get [specific] results. We got to choose measurements and stuff, I guess sometimes, but everything was pretty much 'Read this, do that, you should get this and then write your report on that.'" – Somewhat motivated student, GTA: Puffin*
GTA supports *Autonomy*: GTA guided and encouraged students to come to figure things out themselves.	*"Our GTA is amazing. I knew if I didn't understand something, I could go to them and they would explain it to me in another way. They wouldn't just straight-up give us the answer, they would help us. Give us the tools to get the answer, which is pretty good for me. I like learning that way." –Highly motivated student, GTA: Shell*
GTA does not support *Autonomy*: GTA did not facilitate students' independent troubleshooting, skill-building, or learning.	*"[Our GTA] wanted to make sure everybody was doing everything correctly…. Sometimes, I think they would get a little frustrated and just go in there and do it for us really quick…But I think if they were looking to provide the full benefits of a research-based course, they should have been more explanatory, as opposed to just going in and doing it." – Amotivated student, GTA: Kelp*
RELATEDNESS	
GTA supports *Relatedness*: GTA demonstrated investment in the course, connected with students, and created an environment to foster student community and comfort within the lab.	*"[Our GTA] always said to feel free to ask questions to anybody, because we're all doing the same thing… if we had a question, we were openly able to ask it, and [the GTA] would direct us to other groups on the same protocol. They wanted us to feel comfortable, that it wasn't just me and my partner doing [the experiment], but the whole class, and we should feel comfortable asking questions to everybody." –Highly motivated student, GTA: Urchin*
GTA does not support *Relatedness*: GTA demonstrated behavior and/or an attitude that also created an environment that made student feel uncomfortable in the lab or asking questions.	*"Our GTA seems like they don't want to be [in class] …When their overall attitude is, 'I don't want to be here,' our attitude is going to be that as well." –Amotivated student, GTA: Urchin*

* Quotes have been lightly edited for grammar and concision.

Table 6-3. *Themes related to experiencing essential CURE elements*

Perception of CURE element	Student Quote*
SCIENTIFIC TOOLS AND PRACTICES	
Present	*"We used a lot of protocols and use different things like a centrifuge. It made me feel like I kind of get to be a real scientist, getting to do these experiments." –Highly motivated student, GTA: Urchin*
Limited	*"Honestly, the only things that I really know how to do are micropipette and maybe a plaque assay… I don't think I learned a lot of scientific things. I could micropipette if you asked me to, but that's about the extent of what I know how to do." –Amotivated student, GTA: Urchin*
COLLABORATION	
Present	*"Our TAs were really big on collaboration and trying to kind of figure things out for yourself. They would help us with certain techniques and encouraged us to kind of work with our peers before we came to them to try to figure out our own answer." –Highly motivated student, GTA: Coral*
Limited	*"The only people I really talked to in that class were the people that were at my table, and we kind of helped each other out. People were encouraged to talk to one another, but nobody ever really did it. I think it would have been helpful if I could have talked to [other groups]." –Somewhat motivated student, GTA: Kelp*
ITERATION	
Present	*"From my understanding, repeating trials over and over again to get your desired result is exactly what research is and what we did." –Somewhat motivated student, GTA: Wave*
Limited	*"If we did not find phage, we were able to continue collecting soil samples to try find phage. [Eventually], we were given a (practice) phage. After that point we did not have much opportunity to repeat the processes, just because of the timeframe." –Amotivated student, GTA: Wave*
SCIENTIFICALLY RELEVANT NOVEL DISCOVERY	
Present	*"It was really cool to learn what bacteriophage were and where they fit in to science and medicine. Unlike other labs, the [CURE] created an incentive: if you were able to get a phage and purify it, and do all the steps correctly, then you could be contributing to something bigger." –Highly motivated student, GTA: Coral*
Limited	*"We were contributing to phage research in the [online] database, but at the same time, there were so many other students who had already contributed phages. It seemed like ours wasn't really going to be very significant, in comparison to all the others." –Highly motivated student, GTA: Wave*
Absent	*"It mostly felt like we were imitating real research rather than just actually doing research… it kind of just felt like something I would do in high school, that didn't really contribute much." –Amotivated student, GTA: Sand*

* Quotes have been lightly edited for grammar and concision.

Table 6-4. *Student outcomes of finding a novel phage or adopting a practice phage often impacted their intrinsic motivation in the course*

Codes related to experience of finding a novel phage	Example Quote*
Adopting a practice phage decreased Intrinsic motivation: Adopting a practice phage, rather than finding one's own, made the CURE feel less scientifically relevant, less interesting, less important, or decreased feelings of ownership.	*"When [I was working with my own] soil sample, I was excited, because I [knew we collected it near] a food source. I was excited to see how many phages are by food sources, and if it's similar to other places that have food sources. When it came to using the [class practice] phage, I didn't know where it was from, so I didn't really get to have that connection with [the phage]." –Highly motivated student, GTA: Urchin*
Finding a novel phage increased Intrinsic motivation: Finding a phage made the CURE feel relevant, exciting, and increased student investment and ownership in the class.	*"[The CURE is] cool too, because we get to name [the phage] and it's a lot more exciting. It makes me feel more compassionate about the lab, because I found my own phage and I'm so connected to it. [The effort of finding a phage] made me more interested in the lab." –Highly motivated student, GTA: Shell*
Outcome did not impact student motivation: Student reported that their motivation and feelings about the class were not significantly impacted by either finding a novel phage or being given a practice phage.	*"I don't think [my class experience would be different if I found a phage], just because I wouldn't really be doing anything with it afterwards. I think just performing the experiments and knowing what could happen with what people have discovered is enough for me. I don't think that actually discovering [a phage] would have made a difference. –Highly motivated student, GTA: Krill*

* Quotes have been lightly edited for grammar and concision.

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Chapter 7

Discussion

As we accumulate evidence of the benefits of employing evidence-based teaching strategies into undergraduate biology curriculum, there have been calls for research to increase our understanding of why, how, and in what contexts these strategies are effective for students, and to study how instructors gain the skills necessary to teach using evidence-based teaching practices such as CUREs (Dolan, 2015). Each chapter in this work aims to address this call, by expanding our knowledge of the elements of CURE design and instruction that motivate students and contribute to their perceptions of engaging in authentic research, and by considering the practical necessity and impacts of using GTAs as CURE instructors.

Below, I discuss three themes that have been central throughout multiple chapters of this work: 1) the role of relevant discovery and failure in a CURE; 2) barriers to GTA's adoption of evidence-based teaching, including CUREs; and 3) impacts of GTAs on students' experiences in a CURE. I additionally offer suggestions—for researchers and practitioners—related to each theme.

Theme 1: The Role of Relevant Discovery and Failure in a CURE

"Authenticity" can be a contentious word in the context of implementing research-based courses. Perceptions of authenticity can emerge for students in different educational contexts, and students, instructors, and scientists may have different interpretations of what it means to engage in an "authentic" research experience (Auchincloss et al., 2014; Rahm et al., 2003). For this reason, in defining the five elements essential to a CURE, Auchincloss and colleagues (2014) deliberately used the phrase "broader relevance" rather than the word "authenticity" to describe the element of integrating a larger scientific purpose in the research projects that students engage in through a CURE. Because CUREs are intended to provide students with a legitimate opportunity to engage in scientific research, we aimed to understand if students in a CURE actually believe they are participating in "real" research. Therefore, in Chapter 2, we consider the experiences that promote perceptions of authenticity for students in an independent CURE, and propose an alignment of existing frameworks of authenticity in order to describe how the different experiences of Inquiry and CURE students may still feel "authentic" from the perspective of a student.

The elements of *Broader Relevance* and *Novel Discovery* (collectively, *Relevant Discovery*) distinguish CURE curriculum from Inquiry curriculum, and by integrating these elements into the curricula, experts intend to provide students with an experience that is more similar to an apprentice-based research experience in faculty-led research labs (Auchincloss et al., 2014; Brownell & Kloser, 2015; Goodwin et al., 2021). As described in Chapter 2, the majority of students in our independent CURE felt that they had conducted "real" scientific research in the CURE. However, the element of *Relevant Discovery* was not the primary element students connected to their descriptions of why their experiences felt authentic. Instead, experiences with *Failure*, *Iteration*, and *Scientific Practices* surpassed *Relevant Discovery* in contributing to student perceptions of authenticity (Figure 2-2). *Failure* is a topic of high interest, as recent work reveals the potential benefits of offering students opportunities to deal with and learn from failure, and increased learning gains have been demonstrated for students in a CURE who have opportunities to deal with challenges and failure (Gin et al., 2018; Henry et al., 2019). We were therefore particularly interested in students' explanations of why *Failure* contributed so strongly to perceptions of authenticity. While analyzing students' written reflections, we noticed that students often connected *Failure* to the *Relevant Discovery* built into the CURE: While *Relevant Discovery* itself was not the most critical direct contributor to perceptions of scientific authenticity, it provided a context in which students could productively experience and learn from *Failure*, because students were conducting relevant and novel experiments.

In Chapters 5 and 6, we continued to explore students' experiences with *Relevant Discovery* and *Failure*. While in Chapter 2, we explored these elements in the context of an independently developed CURE that closely aligned with a faculty member's research program, the case study described in Chapters 4, 5, and 6 was conducted in the context of a network CURE using the HHMI SEA-PHAGES curriculum—a "packaged" curriculum that can be implemented at many institutions. As in the independent CURE, students in the network CURE experienced a high rate of failure, and few "successfully" met the goal of isolating and characterizing their own bacteriophage. However, we found that students in network context had a very different reaction to failure compared to students in the independent CURE: students in the network CURE found failure to be a demoralizing experience that decreased their interest in the class (Chapter 6, Figure 6-5). In explaining their negative reaction to failing to find a phage, students often described a loss of connection and ownership to their work when they ultimately failed in isolating their own phage and had to continue their work using a class stock phage (Table 6-4). These students were aware that the work they were doing with the class stock phage no longer had potential to contribute new information to the online phage database—in other words, students no longer perceived *Relevant Discovery* in their work.

We interpret this finding as further evidence that students' reaction to failure is linked to their perceptions of the element of *Relevant Discovery,* as proposed in Chapter 2. While the element of *Relevant Discovery* has been proposed to be a key element in increasing feelings of project ownership in a CURE (Cooper et al., 2019), this work highlights the additional importance of *Relevant Discovery* in the CURE curriculum as a potential element that allows students to more productively experience and learn from *Failure* in their course.

Relevant Discovery in the SEA-PHAGES Curriculum

As we learned through the GTA interviews, student lab objectives worksheets, and student interviews, discussed in Chapters 5 and 6, students and GTAs alike perceived a lack of *Relevant Discovery* in the SEA-PHAGES network CURE curriculum (Figures 5-2 and 6-4; Table 5-3). SEA-PHAGES is a widely used network curriculum, and has many benefits for students (Hanauer et al., 2017; Jordan et al., 2014; Staub et al., 2016). However, in Chapters 5 and 6, I propose that the scaffolded element of *Relevant Discovery* is a weakness of this curriculum, which may be susceptible to being lost entirely depending on the context of each individual implementation of SEA-PHAGES curriculum at different institutions. If *Relevant Discovery* is weak or absent, the curriculum may be more similar to an inquiry course, rather than a CURE course, and therefore may not provide students with the research experience intended in offering a CURE (Auchincloss et al., 2014; Brownell & Kloser, 2015; Cooper et al., 2019; Goodwin et al., 2021).

Theme 1. Implications for Researchers and Practitioners

Further research should explore student and instructor perceptions of *Relevant Discovery* in other iterations of SEA-PHAGES and in other network CUREs, and compare perceptions of *Relevant Discovery* in network CUREs and independent CUREs. Researchers should question if the SEA-PHAGES curriculum sufficiently scaffolds each of the five essential design elements of a CURE (Auchincloss et al., 2014), or whether it may more closely align with the structure of an inquiry course, as outlined in Chapter 2 (Goodwin et al., 2021). While there is certainly evidence that the SEA-PHAGES curriculum benefits students (Hanauer et al., 2017; Jordan et al., 2014; Staub et al., 2016), practitioners who wish to provide their students with the experience of a CURE should question whether this curriculum sufficiently meets that goal, and/or should consider ways to strengthen the element of *Relevant Discovery* when implementing SEA-PHAGES as a CURE.

Researchers should also continue to test the hypothesis that *Relevant Discovery*, when sufficiently scaffolded, is an element that can help students learn productively and benefit from experiences of *Failure*. Understanding the impacts of the elements of *Relevant Discovery* and *Failure* may be key in explaining how CUREs function to benefit students.

Theme 2. Barriers to GTA's Adoption of Evidence-Based Teaching, Including CUREs

Prior to this work, research on how instructors change their instructional practices and adopt evidence-based teaching focused on faculty, rather than graduate students (Andrews & Lemons, 2015; Henderson & Dancy, 2007; Lund & Stains, 2015). Through interviews with graduate students about their experiences with evidence-based teaching practices, we found that graduate students generally value and have interest in employing evidence-based teaching (EBT) techniques, but several barriers prevent many GTAs from actually adopting these practices into their teaching (Chapter 3, Figure 3-2; Goodwin et al., 2018). These barriers can include: a lack of training; a lack of opportunities to teach; perceptions that EBT practices are not compatible with specific types of courses; perceptions of limited autonomy to incorporate EBT into their courses; and perceptions that GTAs should be prioritize their research, rather than invest in using evidence-based teaching practices, while in graduate school (Goodwin et al., 2018).

In considering CUREs specifically, this work builds on prior research of the experiences and perceptions of faculty members who teach CUREs (Shortlidge et al., 2016, 2017), and contributes to a small number of recent studies that directly address the experiences and impacts of GTAs of CUREs (Esparza et al., 2020; Heim & Holt, 2019). In parallel to our findings about how GTAs adopt evidence-based teaching practices (Chapter 3), in Chapter 4 we found that the majority of nine GTAs who participated in our CURE case study perceived high value in the CURE, often both for their students and for themselves (Table 4-3). However, for a few of the GTAs, perceiving high value in the experience did not necessarily equate to an ability to embrace their role in acting both as a Student Supporter and as a Research Mentor in the CURE (Chapter 4, Figure 4-3), or in their capacity to create a supportive classroom environment and emphasize critical elements of the CURE (Chapter 5, Figures 5-1 and 5-3). GTAs were not necessarily aware of their own limitations in their capacity as a CURE GTA, particularly in terms of their ability to create a supportive learning environment, foster student autonomy and competence, and to facilitate the essential components of the CURE. Therefore, there are likely additional barriers–that GTAs may be unaware of or were unwilling to share during interviews—that prevent some GTAs from fully succeeding as a CURE instructor. Below, we explore two potential barriers:1) professional development and support, and 2) buy-in to the philosophy of teaching using CUREs.

Potential Barrier #1: Professional development may not align with the needs of CURE GTAs

In Chapter 4, GTAs reported feeling that they had sufficient training and support to be confident and capable in their ability to teach the CURE, particularly after having experienced the curriculum at least once (Table 4-1). Indeed, GTAs in this case study received significant training and support from the faculty instructor, and lab coordinator: in addition to participating in a week of "boot camp" training at the beginning of the term, where they gained familiarity with the curriculum, they participated in weekly TA meetings, and could rely on asking the lab coordinator for help when needed. However, as we saw in Chapter 3, participation in required TA training still can result in failure of GTAs to fully adopt evidence-based teaching practices. Further, it is possible that the training that GTAs receive and the support they seek out are focused on the technical aspects of facilitating the CURE, and do not sufficiently address other aspects that might be most necessary to support students. In Chapters 4 and 6, we explore the capacity of GTAs to support students while teaching a CURE using two different frameworks: In Chapter 6, we use Self-Determination Theory to consider how supporting students' basic needs of *Competency, Autonomy*, and *Relatedness* impacts students' motivation in the CURE. These three basic needs align with the two dimensions of the mentor role that we propose are ideally balanced by a CURE GTA in Chapter 4: the "Student Supporter," who supports students' comfort in the classroom and affective needs (akin to *Relatedness*); and the "Research Mentor," who develops student's independent research skills (akin to *Competency* and *Autonomy*). Based on the findings regarding the variation in GTA's perceptions of their role in the classroom (Chapter 4, Figure 4-3) and student perceptions of their GTA's ability to support their learning (Chapters 5 and 6, Figures 5-1 and 6-3), GTA training and support efforts may need to increase focus on teaching GTAs how to fulfill these roles as a mentor in order to best meet the needs of CURE students.

Potential Barrier #2: "Value" may not equate to buy-in for GTAs teaching CUREs

A known barrier to promoting change in teaching practices occurs when instructors do not understand or agree with the philosophy of the evidence-based teaching practices they are meant to adopt (Henderson et al., 2011). We observed a blatant example of this barrier in only one GTA in our case study. The single GTA demonstrated a clear lack of value for the CURE, and also did not strongly endorse either the "Student Supporter" or the "Research Mentor" roles (Chapter 4, Figure 4-3). Additionally, their students reported a negative and unsupportive lab environment, and students reported fairly low perceptions of experiencing critical CURE components (Chapter 5, Figures 5-1 and 5-

3). However, while clear negative perceptions of the CURE should be a warning sign that the GTA may not be able to adequately teach the CURE, a few of the other GTAs who expressed value for the CURE also struggled to create a positive learning environment or support student experiences with critical CURE elements. For some of these GTAs, the costs they associated with teaching the CURE may have prevented them from fully buying-in to the philosophy and practice of teaching a CURE—for example, some GTAs discussed feeling frustrated that teaching the CURE took time away from research activities, feeling as though their teaching wasn't valued by the department, and facing difficulties in managing resistance and frustration from students while experiencing *Iteration* and *Failure* in the CURE (Chapter 4, Table 4-2). These costs could be sufficient to deter GTAs from putting adequate effort into creating a supportive learning environment and facilitating the critical elements of a CURE. In particular, student resistance and a desire to please students by protecting them from *Iteration* and *Failure* is a known barrier to GTAs promoting student-centered learning in inquiry courses (French & Russell, 2002; Gormally et al., 2016; Kurdziel et al., 2003). Given that GTAs reported student frustration with *Iteration* and *Failure* as a cost (Chapter 4, Table 4-2) and students reported that they experienced little independent troubleshooting (Chapter 5, Figure 5-2), it seems likely that some GTAs of CUREs may also struggle to promote student-centered learning in a CURE.

Theme 2. Implications for Researchers and Practitioners

As seen in this work, student and instructor perceptions of instructional practices and instructor efficacy in laboratory courses often do not align (Beck & Blumer, 2016; Smith & Delgado, 2021). Therefore, researchers should be wary about using instructors' self-reported enthusiasm and value of evidence-based teaching as sole evidence that those instructors are providing sufficient support to students while employing evidence-based teaching practices. Instead, information about instructor behavior and efficacy should be gathered from multiple sources, including students.

Practitioners who offer teaching professional development for GTAs of CUREs should focus not only on teaching GTAs protocols and how to facilitate the CURE curriculum, but should also teach GTAs to support students' *Competency*, *Autonomy*, and *Relatedness*. Additionally, practitioners should be aware that GTAs who do not appear to "buy-in" to the intentions of the CURE curriculum could be unequipped to fulfill their role as a "Student Supporter" or "Research Mentor," and could have difficulty creating a supportive classroom environment that allows students to benefit from the research experience offered in the CURE. When possible, practitioners should avoid having these GTAs teach CUREs.

Theme 3. Impacts of GTAs on Students' Experiences in a CURE

While a few previous studies have made note of differences in student outcomes or instructional behaviors for students in CURE sections taught by different GTAs (Esparza et al., 2020; Reeves et al., 2018), this work is the first to specifically explore GTA's instructional variation in a CURE, and the impact this variation can have on students. In our case study presented in Chapters 4, 5, and 6, we found variation both in the attitudes and perceptions of individual GTAs who teach CUREs, and in the support individual GTAs provide their students in a CURE. Ultimately, Chapters 5 and 6 demonstrate that the experiences of students in GTA-taught CUREs can be very different depending on GTA, even within a single institutional and curricular context. Findings from Chapters 5 and 6 suggest that students who perceive that their GTA creates a supportive and positive classroom environment are more likely to report experiencing structural elements essential to the CURE model—particularly *Collaboration*, *Iteration*, and *Relevant Discovery* (Figures 5-1, 5-3, 6-3, and 6-4). In Chapter 6, we propose a data-informed model of the impacts of GTA support on student experiences in a CURE (Figure 6-6): perceptions that one's GTA is unsupportive of *Competency*, *Autonomy*, and *Relatedness* in the CURE prevents students from experiencing high autonomous motivation in the CURE and limits experiences of the essential CURE elements. Further, unsupportive GTAs could be particularly harmful to students who enter the class with lower scientific self-efficacy, lower interest in science, and lower understanding of the potential benefits of participating in research experiences.

The GTAs in our study were complex individuals, with perspectives that sometimes conflicted with their actions and did not always predict their student's experiences in their classes. While it is difficult to observe clear and exact patterns between a GTA's value for the CURE, understanding of their role, and their student's experiences, there were some trends in our findings across analyses described in Chapters 4, 5 and 6: students of roughly a third of the GTAs reported a highly supportive classroom environment (Figure 5-1), higher engagement with the critical elements of the CURE (Figure 5-4), and, in interviews, were generally at least "somewhat motivated" to engage in the CURE (Figure 6-2). These GTAs additionally seemed to perceive that their role as a CURE instructor was both to support students emotionally and to develop students as researchers (Figure 4-3). At the other end of the spectrum, approximately a third of the GTAs perceived high costs in the CURE or had misconceptions about their role in the classroom (Figure 4-3), and their students described a less supportive classroom environment (Figure 5-1) and perceived experiencing the critical CURE elements to a lesser degree (Figure 5-4). Findings from a case study involving a small sample size of nine GTAs within a single context are unlikely to describe the full range of experiences and impacts of GTA-taught CUREs at other institutions and with different CURE curricula. However, this work suggests that while some GTAs may struggle in teaching the CURE, resulting in negative experiences for their students, other GTAs appear to be capable of handling the challenges associated with teaching a CURE and positively supporting their students' experiences.

Theme 3. Implications for Researchers and Practitioners

Researchers should further explore the equity of the research opportunities provided by CUREs, and how the quality and benefits of a CURE research experience are impacted by the capacity of individual GTAs. CUREs are intended to increase equity in access to research for undergraduates, but this could be threatened if GTAs do not sufficiently support their students in a CURE.

Practitioners who lead GTA-taught CUREs should consider additional ways to support students, in order to mitigate potential inequities introduced by unsupportive GTAs. Instructors could consider scaffolding additional support for students' *Competency, Autonomy*, and *Relatedness* in an associated lecture component of the class (if one exists), or further integrating support for these elements into the curriculum that GTAs teach.

Conclusion

GTA-taught CUREs offer the potential to scale-up opportunities to participate in research and increase equity in access to research opportunities for undergraduates through introductory biology lab curriculum. We found that while GTAs who are particularly unprepared or unwilling to teach CUREs are likely to negatively impact their student's experiences, other GTAs have the capacity to create supportive experiences for their students and facilitate the essential CURE elements of *Collaboration*, *Iteration*, and *Relevant Discovery*. While practitioners may need to expand professional development for their GTAs and consider ways to increase support both for GTAs and students, our findings demonstrate that students can have positive research experiences in GTA-taught CUREs when supported by competent GTAs.

In addition to benefitting students, GTA-taught CUREs are likely to provide rich opportunities for the GTAs themselves. Experience teaching, regardless of the curriculum, can benefit graduate students in developing their research skills (Feldon et al., 2011; Shortlidge & Eddy, 2018). Teaching research-based curriculum may increase these benefits for GTAs: GTAs of CUREs—both in our case study, and at other institutions—have reported benefiting from the increased autonomy they experience while teaching a CURE and increased competency as a researcher, a teacher, and a research mentor (Chapter 4; Goodwin & Shortlidge (unpublished data); Heim & Holt, 2019). In providing opportunities to develop these skills, CUREs could be a valuable tool to prepare graduates students for an academic career, for GTAs who intend to continue in academia (Austin, 2002).

Could teaching CUREs help GTAs progress toward adopting evidence-based teaching?

CUREs also offer an opportunity to address some of the barriers GTAs face in efforts to adopt evidence-based teaching. GTAs in Chapter 2 reported lack of autonomy, training, and support as barriers to adopting evidence-based teaching practices. Therefore, the increased autonomy experienced when teaching a CURE, along with the student-driven structure of a CURE, could provide an opportunity for GTAs to move away from didactic teaching and practice evidence-based and student-centered teaching. CUREs can also offer increased opportunities to train and support GTAs, as faculty CURE instructors and GTAs in our study have highlighted the importance of a supportive environment in order to successfully teach a CURE (Shortlidge et al., 2016; Chapter 4). Faculty facilitators of GTA-taught CUREs should integrate additional support for GTAs to adopt evidence-based training through CURE-specific pedagogical training, both before and during the course. Offering such support as GTAs teach CUREs will improve the capacity of GTAs to effectively teach CUREs, and consequently support their student's experiences in a CURE.

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Appendices

Appendix A.1: Laboratory Course Assessment Survey (LCAS) Items

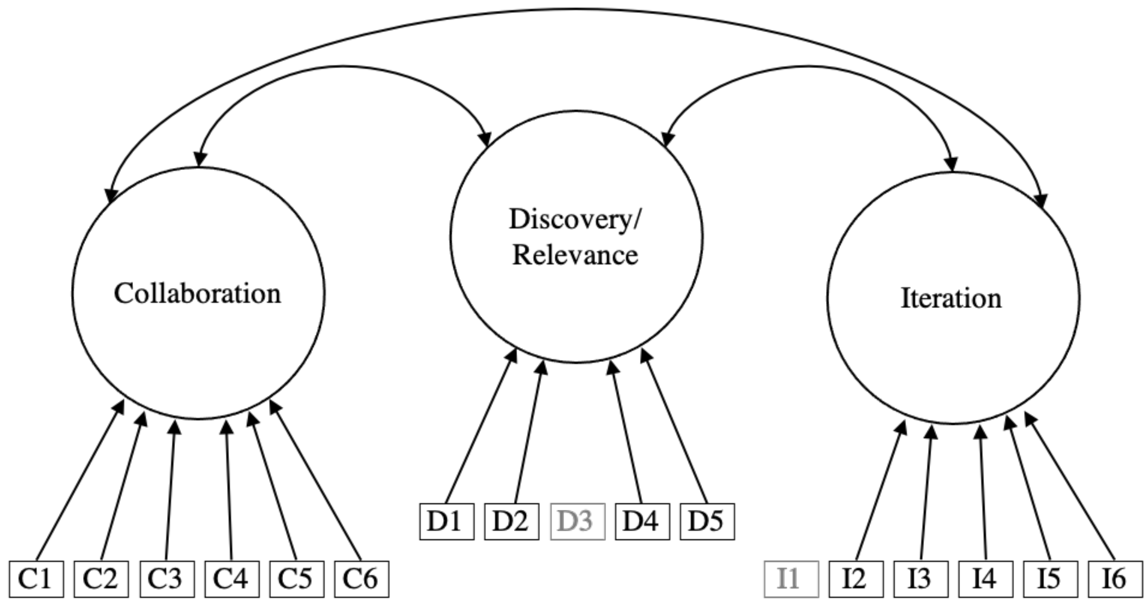
Adapted from Corwin et al., 2015:

Construct	Prompt	Item #	Item Text	Item Response Options
Collaboration	I was encouraged to…	C1	discuss elements of my investigation with classmates or instructors	1#: Never 2: Only once 3: A couple of times, but not every lab period 4: About once per lab period 5: Multiple times during most lab periods
		C2	reflect on what I was learning	
		C3	contribute my ideas and suggestions during class discussions	
		C4	help other students collect or analyze data	
		C5	provide constructive criticism to classmates and challenge each other's interpretations	
		C6	share the problems I encountered during my investigation and seek input on how to address them	
Discovery/Relevance	I was expected to…	D1	generate novel results that are unknown to the instructor and that could be of interest to the broader scientific community or others outside of class	1: Strongly disagree 2: Disagree 3: Somewhat disagree 4: Somewhat agree 5: Agree 6: Strongly agree
		D2	conduct an investigation to find something previously unknown to myself, other students, and the instructor	
		D3*	formulate my own research questions or hypothesis to guide an investigation	
		D4	develop new arguments based on data	
		D5	explain how my work has resulted in new scientific knowledge	
Iteration		I1*	revise or repeat work to account for errors or fix problems	
	I had time to…	I2	change the methods of the investigation if it was not unfolding as predicted	
		I3	share and compare data with other students	
		I4	collect and analyze additional data to address new questions or further test hypotheses that arose during the investigation	
		I5	revise or repeat analyses based on feedback	
		I6	revise drafts of papers or presentations about my investigation based on feedback	

**Indicates items D3 and I1, which were removed from analyses in Chapter 2. I1 is included with the* Discovery/Relevance *items in this table due to the common question stem ("I was expected to…. ").*
#*Original* Collaboration *response options: 1= Weekly; 2= Monthly; 3= One or two times, 4= Never.*

Appendix A.2: LCAS Correlated Three-Factor Model

Adapted from Corwin et al., 2015



We used the Laboratory Course Assessment Survey to test a correlated three-factor model of *Collaboration, Relevant Discovery,* and *Iteration*. Boxes with item numbers represent the survey items that serve as indicators for each latent factor. Two items (D3 and I1, in grey) were not included in our final model.

Appendix A.3: Participant demographics and chi-square tests of independence

Demographics[a]	Inquiry students N = 302	CURE students N = 74	χ^2 test results
	N (%)	N (%)	
Legal sex[b]			
Female	179 (59.3)	47 (63.5)	$\chi^2 = 0.33$, $p = 0.565$
Male	120 (39.7)	27 (36.5)	
Race/ethnicity[c]			
Underrepresented minority (URM)	62 (20.5)	12 (16.2)	$\chi^2 = 0.69$, $p = 0.403$
Non-URM	240 (79.5)	62 (83.8)	
Generation status			
First generation	103 (34.1)	22 (29.7)	$\chi^2 = 0.21$, $p = 0.648$
Continuing generation	147 (48.7)	36 (48.6)	
Transfer status			
Transfer undergraduate	110 (36.4)	30 (40.5)	$\chi^2 = 1.49$, $p = 0.222$
Non-transfer undergraduate	156 (51.7)	30 (40.5)	
Post-baccalaureate			
Post-bac	35 (11.6)	14 (18.9)	$\chi^2 = 2.81$, $p = 0.093$
Undergraduate	267 (88.4)	60 (81.1)	
Major			
Biology	162 (53.6)	43 (58.1)	$\chi^2 < 0.42$, $p = 0.516$
Other STEM major	130 (43.0)	29 (39.2)	

[a] Unless otherwise stated, data was obtained from the institutional database. Percentages in each demographic group may not add up to 100% due to missing student information for certain demographic categories. [b] We were unfortunately only able to obtain legal sex information from our institution, which likely mischaracterizes the gender identity of some of our participants. [c] Students who identified as Hispanic/Latino, Native American/Alaskan/Hawaiian, Black or African American, and Pacific Islander were classified as underrepresented minorities (URM).

Appendix A.4: LCAS Item Summary Statistics

Summary statistics for items in each of the three LCAS constructs are included in the tables below. Suggested interpretations of skewness and kurtosis when evaluating normality of data vary widely. Overall, our items show little skew (all absolute skewness values are less than 2.0), and some kurtosis (ranging between 1.6 and 5.5). Acceptable absolute kurtosis values for normal data range from below 2.0 ("conservative", Hancock et al., 2018) to below 7.0 ("liberal", Hancock et al., 2018) or even below 10.0 ("conservative"; Kline, 2015). To account for this moderate non-normality of our data, we used a robust estimator in our confirmatory factor analyses.

Collaboration Item Summary Statistics

Items	Group	Mean	SD	Median	Min	Max	Skewness	Kurtosis
C1	CURE	4.65	0.61	5	3	5	-1.54	4.22
	Inquiry	4.28	0.94	5	1	5	-1.25	4.11
	Total	4.34	0.90	5	1	5	-1.36	4.47
C2	CURE	4.60	0.58	5	3	5	-1.14	3.31
	Inquiry	4.15	0.95	4	1	5	-1.12	4.16
	Total	4.23	0.91	4	1	5	-1.23	4.54
C3	CURE	4.35	0.90	5	2	5	-1.14	3.22
	Inquiry	3.95	1.13	4	1	5	-1.05	3.51
	Total	4.02	1.10	4	1	5	-1.10	3.64
C4	CURE	4.33	0.99	5	1	5	-1.57	4.97
	Inquiry	4.33	0.91	5	1	5	-1.40	4.93
	Total	4.33	0.92	5	1	5	-1.44	4.96
C5	CURE	4.02	1.06	4	1	5	-1.02	3.81
	Inquiry	3.56	1.25	4	1	5	-0.56	2.44
	Total	3.65	1.23	4	1	5	-0.64	2.59
C6	CURE	4.42	0.79	5	2	5	-1.17	3.54
	Inquiry	4.03	1.09	4	1	5	-1.05	3.58
	Total	4.10	1.05	4	1	5	-1.13	3.80

Iteration Item Summary Statistics

Items	Group	Mean	SD	Median	Min	Max	Skewness	Kurtosis
	CURE	5.40	0.73	6	3	6	-1.13	4.13
I1	Inquiry	4.50	1.28	5	1	6	-0.87	3.37
	Total	4.66	1.25	5	1	6	-1.00	3.69
	CURE	5.23	0.84	5	3	6	-0.70	2.46
I2	Inquiry	4.31	1.34	4	1	6	-0.71	2.95
	Total	4.48	1.31	5	1	6	-0.82	3.19
	CURE	5.37	0.69	5	4	6	-0.63	2.28
I3	Inquiry	4.99	1.01	5	1	6	-1.32	5.45
	Total	5.06	0.97	5	1	6	-1.36	5.71
	CURE	5.28	0.80	5	3	6	-0.82	2.94
I4	Inquiry	4.54	1.30	5	1	6	-0.93	3.27
	Total	4.68	1.26	5	1	6	-1.04	3.61
	CURE	5.26	0.69	5	4	6	-0.38	2.13
I5	Inquiry	4.24	1.36	4	1	6	-0.60	2.55
	Total	4.42	1.33	5	1	6	-0.77	2.87
	CURE	5.44	0.67	6	4	6	-0.77	2.50
I6	Inquiry	4.04	1.47	4	1	6	-0.37	2.15
	Total	4.29	1.46	5	1	6	-0.58	2.35

Discovery Item Summary Statistics

Items	Group	Mean	SD	Median	Min	Max	Skewness	Kurtosis
	CURE	5.14	0.80	5	4	6	-0.25	1.62
D1	Inquiry	4.23	1.31	4	1	6	-0.47	2.62
	Total	4.39	1.28	4	1	6	-0.60	2.81
	CURE	5.40	0.69	6	4	6	-0.70	2.33
D2	Inquiry	4.67	1.15	5	1	6	-0.93	3.79
	Total	4.80	1.12	5	1	6	-1.03	4.08
	CURE	5.19	0.76	5	4	6	-0.32	1.81
D4	Inquiry	4.83	0.98	5	1	6	-0.91	4.27
	Total	4.89	0.96	5	1	6	-0.91	4.31
	CURE	5.28	0.67	5	4	6	-0.37	2.24
D5	Inquiry	4.63	1.15	5	1	6	-0.89	3.86
	Total	4.74	1.10	5	1	6	-1.00	4.21

Appendix A.5: Reliability estimates for LCAS scales

McDonald's Omega was used to estimate reliability for all three subscales of the Laboratory Course Assessment Survey (Komperda et al., 2018). In general, reliability coefficients above 0.8 are "very good", indicating that all three subscales have acceptable internal consistency for these analyses (Kline, 2015). McDonald's Omega total for *Collaboration, Iteration*, and *Discovery/Relevance* was 0.86, 0.89, and 0.90 respectively.

Appendix B.1: Graduate Student Interview Questions

1. How far along are you in your graduate program? Tell me a little bit about what you study.
2. During your time as a graduate student, have you been a teaching assistant or held another teaching appointment? What did you teach?

Degree of awareness about evidence-based teaching techniques

3. Now that you are a graduate student, have you noticed any changes in science education from your time as an undergraduate student? What kinds of changes have you noticed?
4. Tell me about your level of familiarity with the concept of student-centered teaching practices versus instructor-centered teaching practices?
5. Student-centered teaching strategies are on the rise in educational institutions of all levels. Why do you think that is?
6. How do you think these instructional changes will affect science classrooms in the future?
7. Can you describe a time when you saw a particular teaching strategy used effectively? What made this strategy effective?

Level of training and experience

8. How would you describe your graduate training in various instructional strategies?
9. Who is the person, or people, in your graduate program that trains you in teaching practices?
10. Have you had any influence on your department and/or PI as it relates to teaching practices?
11. Are you confident as an instructor? What do you think might help you to gain more confidence in teaching?
12. Imagine that you are assigned to teach a general biology course next term. You have full control over the course structure. Would you be confident in your ability to design the curriculum and teach the course? What kinds of instructional strategies would you use and why?
13. What type of professional development do you get? What is optional and what is mandatory?

Perception: Is training in evidence-based teaching techniques important for achieving career goals?

14. What do you feel are the strongest aspects of your graduate training program?

15. Do you think your graduate training has prepared you for being a research faculty member at an institution of higher education? What about for being a teaching faculty member?
16. After graduate school, what are your professional goals? For these goals, do you think it will be important to have received training in student-centered teaching?
17. If you could make suggestions to improve your graduate training program in preparing you for your career, what would you suggest?

Demographics

18. What institution do you currently attend? What degree are you pursuing?
19. What is your age?
20. Do you identify as male, female, or transgender?
21. What race/ethnicity best describes you?
22. What is your primary language spoken at home?
23. How long have you lived in the United States?
24. Are there any faculty members at your institution who might be valuable to reach out to with regard to student-centered teaching strategies and/or graduate level teaching instruction?

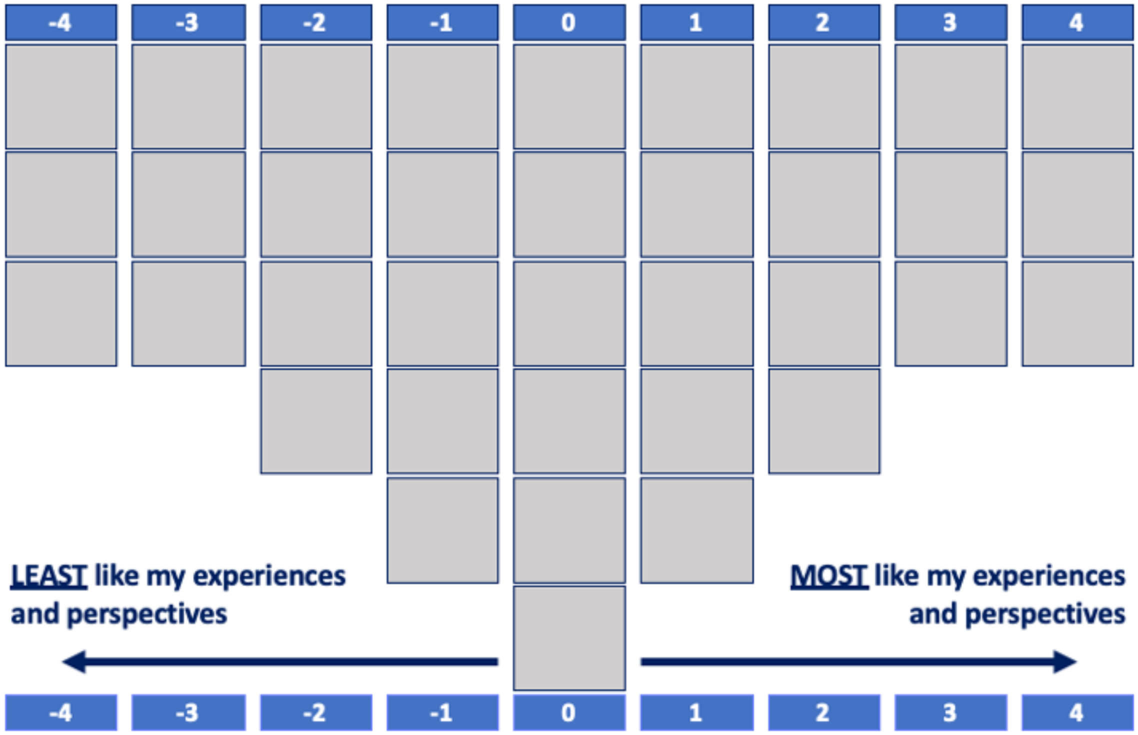
Appendix C.1: GTA Interview Card Sort Statements

EVT Construct (Sub-Construct)	Card statement[1]
Attainment (Ideals)	I think research-based courses like the CURE are valuable because they allow for increased numbers of students to gain research experience.
	I think research-based courses like the CURE are the best way to teach undergraduate biology labs.
	I think research-based courses like the CURE are important because they allow undergraduates to develop skills that will be important in their future.
	I think it is important to use teaching practices that are supported by research on teaching and learning.
	I think it is important for undergraduates to experience research in their classes.
Attainment (Identity)	Teaching the CURE allows me to connect my research and teaching identities simultaneously.
	Teaching the CURE aligns with my identity as a researcher.
	Teaching the CURE aligns with my identity as a teacher.
	I intend to have teaching to be a significant part of my future career.
	I strive to be an excellent teacher.
Intrinsic	It is fulfilling to see students get engaged with their projects in the CURE.
	Teaching the CURE is rewarding.
	Teaching the CURE is intellectually stimulating.
	Teaching the CURE is enjoyable.
	Teaching the CURE allows me to have a better relationship with my students.
	I would like to continue to teach research-based courses like the CURE in the future.
	I feel more pride as a teacher of the CURE.
	Teaching the CURE is fun.
Utility (Personal Development)	Teaching the CURE broadens my knowledge of biology.
	Teaching the CURE improves my mentoring skills
	Teaching the CURE improves my teaching.
	Teaching the CURE allows me to build a better relationship with faculty at my institution.
	Teaching the CURE improves my research skills.
Utility (Tangible)	Getting paid and/or receiving tuition remission is the primary reason I teach.
	Teaching the CURE could result in me being included on as an author on published research papers related to the class.
	Teaching the CURE looks good on my CV.
	Teaching the CURE will help me in getting a future job.
Cost (Emotional)	The lack of structure makes teaching the CURE challenging.
	I do not always have enough teaching experience or training to be confident in the decisions I make when I teach.

	It can be difficult to get students to be excited about the CURE.
	Teaching the CURE is emotionally exhausting.
	I do not always have the appropriate research skills and expertise to guide my students through their research projects.
	The uncertainty of research makes teaching the CURE challenging.
	I do not always have enough content knowledge (*i.e.* knowledge of bacteriophages or the host species) to provide reliable information to my students.
Cost (Time)	I have more responsibilities in teaching the CURE than I would in a different type of course.[2]
	Teaching the CURE is more work than teaching other types of classes.

[1] Statements have been slightly modified when necessary to preserve anonymity of the course and term. [2] Interviews revealed that GTAs variably interpreted this item as either a cost or a benefit.

Appendix C.2: GTA Interview Card Sort Board



Appendix C.3: GTA Interview Protocol

Card-Sort Specific Questions

1. How did that activity go for you?
2. Could you explain a bit about your reasoning for placing these cards in the "Most like your experiences" end of the grid?
3. Could you explain a bit about your reasoning for placing these cards in the "Least like your experiences" end of the grid?
4. Are there any other thoughts you want to share about these cards and this activity?

General Questions (Post Card Sort)

1. If you were designing your own laboratory course for biology undergraduates, would you use a research-based model like the CURE?
2. What are the most important things that undergraduates should walk away with after participating in the CURE?
3. Do you think your students were doing "real science" in the CURE this term? Why?
4. What are your most meaningful responsibilities as a TA for the CURE?
5. In science education literature, it has been proposed that students in a research-based course should have opportunities for novel discovery, collaboration, project relevance, iteration, and use of scientific practices. Do you think your students had the opportunity to practice each of these things in the CURE this term?
6. What do you see as the role of the undergraduate TA in your classroom?
7. How do you support them in this role?
8. Do you think you would be able to teach this class without an undergraduate TA?
9. Would you recommend this course to others as a good course to TA for?
10. Are there any costs or challenges you've encountered as an instructor for the CURE?
11. Do you think these challenges are encountered in other TA-led classes, or only research-based courses?
12. Are there benefits to you for teaching this course?
13. Has being an instructor for this course helped you develop skills that you think will be useful for your graduate/undergraduate studies or for your future career goals?
14. Has being an instructor for this course had an impact on the way you think or feel about teaching or mentorship?

15. Has being an instructor for this course had an impact on the way you think about your research?
16. If you could have any additional knowledge, experiences or training to improve your instruction for the CURE, what would it be? Why?

Appendix D.1: Student Lab Objectives Task and Items

Student Instructions:

Below is a list of potential Biology 107 laboratory ***learning objectives an instructor may have for their students***. Consider each objective, and mark **three objectives** you believe may be the most important and **three objectives** you believe may be the least important *to your lab instructor.*

Pick **one** of the objectives that you listed as **most important.** Please provide a specific example of how your lab instructor has indicated (verbally or through their actions) that this is a priority for them.

Pick **one** of the objectives that you listed as **least important.** Please provide a specific example or explanation for why you believe this is not a priority for your lab instructor.

Full Lab Objective Item	Shortened Name
Students learn how to analyze and interpret data.	Data analysis/interpretation
Students collaborate with teammates to work on a scientific project.	Collaboration
Students better understand the content of the associated lecture course.	Lecture reinforcement
Students learn if research is a career they would like to pursue.	Career clarification
Students become excited about research and science.	Excitement for research
Students conduct an investigation to discover something previously unknown to the scientific community.	Discovery
Students produce accurate and reliable scientific data.	Produce accurate data
Students enjoy their time in the CURE lab.	Enjoy lab
Students learn the importance of revising or repeating their work to improve the quality of their research.	Values iteration
Students learn to troubleshoot problems independently.	Independent troubleshooting
Students develop basic lab skills (learn how to pipette, do a plaque assay, etc.).	Scientific practices
Students feel comfortable asking their instructors questions or discussing any problems.	Approachable instructor
Students develop an understanding of bacteriophages and host system.	Understanding bacteriophage system
Students learn the process of conducting research.	Process of research
Students work on a research project that has the potential to make a real contribution to the public or the scientific community.	Broader relevance

Appendix D.2: Laboratory Course Assessment Survey (LCAS) Analyses

D.2.1: LCAS Item Summary Statistics

Summary statistics for items in each of the three LCAS scales (Collaboration, Discovery, and Iteration) are included in the table below. Our items show little skew (all absolute skewness values are less than 1.5), and moderate kurtosis (ranging between 2.4 and 4.4). Acceptable absolute kurtosis values for normal data range from below 2.0 ("conservative", Hancock et al., 2018) to below 7.0 ("liberal", Hancock et al., 2018) or even below 10.0 ("conservative"; Kline, 2015). To account for this moderate non-normality of our data, we used a robust estimator in our confirmatory factor analysis.

LCAS Item Summary Statistics

Items	Mean	SD	Median	Min	Max	Skewness	Kurtosis
Collaboration							
C1	3.799	1.068	4	1	5	-0.821	3.251
C2	3.893	0.961	4	1	5	-0.956	3.999
C3	3.530	1.125	4	1	5	-0.495	2.779
C4	3.460	1.214	3	1	5	-0.503	2.557
C5	3.201	1.146	3	1	5	-0.346	2.617
C6	3.619	1.076	4	1	5	-0.65	3.064
Broader Relevance/ Novel Discovery							
D1	4.133	1.256	4	1	6	-0.602	2.884
D2	4.332	1.242	4	1	6	-0.836	3.503
D3	3.883	1.33	4	1	6	-0.366	2.479
D4	3.906	1.256	4	1	6	-0.457	2.797
D5	4.355	1.173	4	1	6	-0.823	3.712
Iteration							
I1	4.692	1.123	5	1	6	-0.862	3.649
I2	4.026	1.312	4	1	6	-0.565	2.694
I3	4.198	1.271	4	1	6	-0.767	3.106
I3	4.198	1.271	4	1	6	-0.767	3.106
I4	4.084	1.31	4	1	6	-0.652	2.923
I5	4.407	1.222	5	1	6	-0.952	3.681
I6	4.640	1.228	5	1	6	-1.215	4.374
I3	4.198	1.271	4	1	6	-0.767	3.106

D.2.2: LCAS Reliability

We use the omega reliability coefficient, rather than Cronbach's alpha, as an estimate of the internal consistency of our three instrument scales, as the omega reliability coefficient is equivalent to Cronbach's alpha when factor loadings are equivalent and avoids bias introduced by Cronbach's alpha when factor loadings are independent (Komperda, Hosbein, et al., 2018; Komperda, Pentecost, et al., 2018). McDonald's Omega total for the Collaboration, Iteration, and Discovery/Relevance subscales was 0.86, 0.88, and 0.88 respectively, indicating that all three subscales have acceptable internal consistency (reliability coefficients above 0.8 are considered "very good"; Kline, 2015).

D.2.3: LCAS Data-Model Fit

While historical recommendations for cut-off values for incremental fit indices such as the comparative fit index (CFI) and the Tucker-Lewis Index (TLI) have suggested that models with values above 0.90 may be acceptable, current sources recommend that values for these indices should be 0.950 or above to indicate good model fit (Hancock et al., 2018; Hu & Bentler, 1999; Schermelleh-Engel et al., 2003). The root mean square error of approximation (RMSEA) is a parsimony-adjusted badness-of-fit index, and guidelines recommend values for the RMSEA should fall at or below 0.08 for "acceptable" model fit and at or below 0.05 for "good" model fit (Hu & Bentler, 1999; Kline, 2015; Schermelleh-Engel et al., 2003).

As seen in the table below, fit indices for our tested three-factor model suggest that though model fit is not terrible, it is at or below recommendations for "acceptable" model fit. We therefore have chosen to not use the LCAS survey data as evidence for claims central to this study, but rather as supporting evidence for other data within this study that show similar trends in the perceptions of students taught by individual GTAs.

Fit Indices	**Data-Model Fit**	**Acceptable Fit Guidelines***
CFI	0.922	≥ 0.950
TLI	0.909	≥ 0.950
RMSEA (90% confidence)	0.080 (0.069-0.091)	≤ 0.080

*As suggested by Schermelleh-Engel et al. (2003) and Hancock et al. (2018)

Appendix E.1: Student Interview Protocol

In the questions below, some class-specific terms used in the original protocol have been replaced with more general terms to conceal potentially identifiable information about the course and increase clarity for a general audience.

Follow-up questions were asked throughout the interview to indirectly learn more about the role the GTA instructor played in the classroom: Were you encouraged to do that behavior? Who encouraged you?

1. What is your major? How far into your undergraduate degree are you?
2. In the CURE lab, when you were working on your bacteriophage project, to what extent did you feel like you were participating in real research?
3. Did you feel like your CURE lab experience was similar to what it is like to do research as a scientist?
4. Do you feel like you had opportunities to use scientific practices?
5. Did you feel like the research project you worked on had a relevance or purpose beyond your lab classroom?
6. Did you feel you had opportunities to collaborate (with scientists or with other students) in this course?
7. Do you feel like your research project addressed a scientific "knowledge gap"—no one in the world knew the answer to your specific research question?
8. Did you have opportunities to repeat experiments if they didn't work perfectly the first time?
9. Do you feel like you had autonomy or control over your work in the CURE lab?
10. If any challenges came up in your CURE lab work, did you generally feel capable of overcoming them?
11. Why do you think your institution has designed CURE lab to incorporate aspects of research experiences?
12. When you reflect back at your time spent in the CURE lab each week, how do you feel about it?
13. What made you feel this way?
14. Did your lab instructors have any impact on the way you felt about the CURE lab?
15. What was your relationship with your TA like?
16. In the focus groups, we asked you to fill out a worksheet asking about which learning objectives or goals you felt were most important to your TA. I have your worksheet, and some of the objectives you picked were…. *(read objectives).*

17. Do you still feel like these are among the most important objectives your TA had for the course?
18. Are there any other important things that you think your TA wanted you to take away from the course?
19. You said these objectives were important to your TA—are they also important to you personally?
20. Do you feel as though you having a positive and beneficial experience in the CURE lab was important to your TA?
21. Do you think your CURE graduate TA is an expert in the process of conducting scientific research? Why?
22. Was your TA an expert in the content that your research project focused on (bacteriophages, the bacterial host system, etc)?
23. Was your TA an expert in teaching the CURE lab to you?
24. Is there anything additionally you would like to add about your experience participating in the CURE lab?

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