Faculty Experiences during the Implementation of an Introductory Biology Course-Based Undergraduate Research Experience (CURE)

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ABSTRACT

Course-based undergraduate research experiences (CUREs) integrate an authentic research experience for students into a laboratory course. CUREs provide many of the same benefits to students as individual faculty-mentored research experiences. However, faculty experiences in teaching CUREs are not as well understood. There are no studies that compare faculty's anticipated experiences to actual experiences, and little comparison of the faculty experience by institution. Through interviews with eight biology faculty from four institutions, the faculty experience in implementing a CURE in an introductory biology laboratory was explored using qualitative analysis. Institutions included: a small, minority-serving, women's, primarily undergraduate university; a small, residential, primarily undergraduate college; a midsized doctoral university; and a large community college. Interviews were conducted at three time points: before professional development (PD), after the initial semester of teaching the CURE, and after teaching the CURE at least twice (1 year later). Faculty described resources, benefits, challenges, and feelings about teaching the CURE. However, anticipated experiences were often not the same as those actually experienced. There were also institutional differences in resources, benefits, challenges, and feelings. Implications for CURE PD include specific content such as strategies for teaching effective research group work, development of student proposals, and student time management.

INTRODUCTION

Undergraduate research experiences (UREs) benefit participants through an increased understanding of the scientific process and content, as well as providing for the development, or expansion, of technical skills related to the process of research (Sadler and McKinney, 2010; Fechheimer *et al.*, 2011; Rodenbusch *et al.*, 2016; National Academies of Sciences, Engineering, and Medicine [NASEM], 2017). As a result, UREs improve student persistence in science (Jones *et al.*, 2010) and lead to increased attendance in graduate school science programs (Russell *et al.*, 2007; Carter *et al.*, 2009).

Notably, positive URE outcomes extend to "persons excluded [from STEM] due to ethnicity or race" (PEER; Asai, 2020) students (Nagda *et al.*, 1998; Carter *et al.*, 2009; Jones *et al.*, 2010) and are often a key academic experience that leads to greater persistence for PEERs (Espinosa, 2011; Chang *et al.*, 2014; Estrada *et al.*, 2018; Hernandez *et al.*, 2018). Unfortunately, UREs are not available to the majority of students majoring in science due to limits on faculty time, institutional space, and financial support (Wei and Woodin, 2011; Spell *et al.*, 2014; McDonald *et al.*, 2019). It is also apparent that PEER students face difficulties in obtaining a faculty-mentored research experience (NASEM, 2017), as these students may have less awareness of URE opportunities or little knowledge of the expectations and benefits of UREs (Bangera and Brownell, 2014). Additionally, PEER students are more likely to report lower socioeconomic status, requiring this group to seek full- or part-time

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employment that interferes with out-of-class activities (Bangera and Brownell, 2014).

Course-based undergraduate research experiences (CUREs) are a possible solution to these problems (Wei and Woodin, 2011; NASEM, 2017). Founded on the empirically demonstrated benefits of participation in undergraduate research, CUREs are curricula developed to bring authentic research into the classroom environment. While the definition of exactly what is required in a CURE varies among researchers, it is generally accepted that CUREs incorporate discovery of new knowledge about a relevant scientific problem using established scientific practices (Harrison *et al.*, 2011; Auchincloss *et al.*, 2014; Linn *et al.*, 2015; NASEM, 2015). CUREs often incorporate the practice of iteration, giving students the opportunity to do experiments more than once in pursuit of their research goals (Auchincloss *et al.*, 2014). Like modern research, CUREs usually involve student collaboration (Auchincloss *et al.*, 2014). To date, CUREs have been developed for all levels of undergraduate students, course sizes, and many scientific disciplines (for some examples, see CURENet, https://serc.carleton.edu/curenet/collection.html).

CUREs result in student benefits similar to those observed with participation in faculty-mentored research: increased self-confidence and self-efficacy, development of a science identity, increased academic performance, science process skills, and STEM persistence (Corwin *et al.*, 2015; Shapiro *et al.*, 2015; Olimpo *et al.*, 2016; Hanauer *et al.*, 2017; Gin *et al.*, 2018). Because a CURE occurs during a regularly scheduled laboratory course, it allows more students to participate in URE without having to actively find a research mentor, funding, or out-of-class time (Bangera and Brownell, 2014). In addition, CUREs can be deployed on a large scale, impacting more students than an individual faculty member can mentor within their own research lab, thereby increasing student accessibility and inclusivity (Wei and Woodin, 2011; Bangera and Brownell, 2014; Rodenbusch *et al.*, 2016; McDonald *et al.*, 2019; Shuster *et al.*, 2019).

Faculty who implement CUREs are categorized into two broad categories: those who develop a CURE (CURE developers) and those who teach a CURE developed by someone else (network CUREs; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020). CURE developers often adapt their own research for a CURE context when developing their CURE (Shortlidge *et al.*, 2017), while network CUREs are often initiated through a national support system (Shortlidge *et al.*, 2016, 2017; Genné-Bacon *et al.*, 2020). There is some evidence that challenges, benefits, and supports during CURE instruction differ somewhat by type of CURE faculty (Shortlidge *et al.*, 2016, 2017; Genné-Bacon *et al.*, 2020).

Faculty Experiences Teaching a CURE

Although student impacts in CUREs are documented, the faculty experience while implementing this best practice is not as well understood (NASEM, 2017). Understanding faculty experiences is important for increasing participation in CUREs. The majority of the faculty experiences documented have been barriers to the implementation of CUREs. These barriers can include time constraints, large class size, number of sections, financial considerations, lack of technical and administrative support, learning new teaching methods, and departmental or institutional support (Govindan *et al.*, 2020; Lopatto *et al.*, 2014; Spell *et al.*, 2014; Goedhart and McLaughlin, 2015; Hensel and Cejda, 2015; Shortlidge *et al.*, 2016; Craig, 2017; Roberts *et al.*, 2019). Most of these challenges were found in some, but not all studies. Particularly contradictory are findings related to colleague, department, and institutional support. Some network CURE studies found these to be a challenge (Lopatto *et al.*, 2014; Craig, 2017), while certain CURE developer studies reported the opposite (Spell *et al.*, 2014; Shortlidge *et al.*, 2016). Time constraints expressed as workload, balancing the multiple responsibilities of a faculty member, preparation time, and time for students to complete the CURE during the laboratory course were reported as challenges throughout these studies. Additionally, CURE developers reported finding a research project amenable to the CURE setting to be a challenge (Shortlidge *et al.*, 2016), while those in network CUREs often report the need to learn new technical skills and subject matter as challenging (Lopatto *et al.*, 2014; Craig, 2017; Genné-Bacon *et al.*, 2020). Student participants also face challenges in the implementation of a CURE: students can be resistant to the change in learning that a CURE represents, can lack interest, can be underprepared for the research context, and can find research to be frustrating (Lopatto *et al.*, 2014; Spell *et al.*, 2014; Shortlidge *et al.*, 2016; Genné-Bacon *et al.*, 2020).

To help combat challenges in CUREs, a variety of teaching resources and support for teaching a CURE are often included in network CURE research, but not in CURE developer studies (Lopatto *et al.*, 2014; Wolkow *et al.*, 2014; Craig, 2017). The centralized system of network CUREs provides the faculty with scientific protocols, teaching resources, and assessments (Lopatto *et al.*, 2014; Wolkow *et al.*, 2014; Craig, 2017). Network CURE faculty find professional development (PD) workshops to be valuable, as well as providing a community of faculty for them to consult (Lopatto *et al.*, 2014; Craig, 2017). When sharing a CURE with local community colleges, CURE developers found that they needed to provide support through PD, scientific background material, additional equipment training, and separate training for support staff surrounding laboratory preparation and setup (Wolkow *et al.*, 2014).

A few studies have examined why faculty persist in teaching CUREs despite the challenges. Faculty persist due to their perception of the benefits of CUREs for their students (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020). Faculty place a high importance on students gaining valuable learning, skills, and engagement from participation in an authentic research experience (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020). They perceive that students learn content, science process skills, and technical skills (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020). Another commonly reported benefit is increased student engagement and motivation (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020). Other perceived student benefits include skills transferable to future careers (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017), improved retention in STEM fields (Shortlidge *et al.*, 2017), and enjoyable and meaningful student experiences (Shortlidge *et al.*, 2017).

Faculty-centered benefits common between network CUREs (Lopatto *et al.*, 2014) and CURE developers (Shortlidge *et al.*, 2016) include contributions to their scientific fields, keeping current with their scientific fields, and career enhancement. In a network CURE, Lopatto *et al.* (2014) also found that the

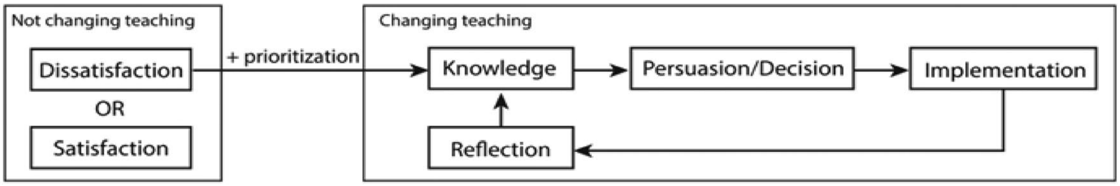

FIGURE 1. The innovation decision process in college science instruction. Andrews and Lemons (2015) faculty decision process framework for the adoption of new pedagogical techniques among college science instructors. There are two main phases: not changing teaching and changing teaching. College instructors need a prioritization event to move from not changing teaching to changing their teaching by potentially adopting a new pedagogical innovation.

faculty enjoyed the scientific community and feasibility of a network CURE. CURE developers reported many benefits to their research programs, such as collecting pilot data for grants; increased publications; recruiting trained students; and merging teaching, research, and service expectations (Shortlidge *et al.*, 2016). In a study with both CURE developers and network CUREs, faculty found teaching CUREs to be rewarding, fun, stimulating, and enjoyable (Shortlidge *et al.*, 2017). Faculty enjoyed their interactions with students and watching them during the process of discovery. CUREs also provided these faculty with a course that matched their science identities (Shortlidge *et al.*, 2017).

Diffusion of Innovations Theoretical Framework

Rogers's *The Diffusion of Innovations* (2003) as adapted by Andrews and Lemons (2015) for college science instruction provides a framework for understanding the adoption process of CUREs (Figure 1). The process starts with a situation of dissatisfaction (or satisfaction) with current teaching practices, but no changes in teaching occur. Given the high demands on faculty time, there must be a reason to move into the decision process (prioritization, Figure 1). Once a change in teaching is prioritized, the adoption process begins. The faculty must be introduced to a possible new teaching strategy. Once an individual is made aware of the existence of an innovation, the newness of the innovation generates a high degree of uncertainty in the individual—particularly about the innovation's cost, relative advantages, and shortcomings and its applications within the context of the individual's circumstances (knowledge, Figure 1). To reduce the degree of uncertainty, the individual enters a period of information gathering, and in the course of attaining knowledge about the innovation, forms an attitude toward it (persuasion/decision, Figure 1). Once the initial decision to try the innovation is made, then implementation of the new teaching strategy occurs (implementation, Figure 1). During this process, the faculty member continues to assess the experience, gathers more knowledge, and reflects on how well the new teaching strategy is meeting goals (reflection, Figure 1). The end objective of this innovation–decision process is to evaluate the innovation and determine whether to adopt or reject it. Andrews and Lemons proposed that, in college science instruction, this is a cyclical process in changing teaching. However, an innovation may be discarded at any point in this process (Rogers, 2003). A major point in this process is the implementation stage. For CURE faculty, this occurs the first time they teach the CURE. They are most likely to compare it to their prior laboratory teaching experiences, evaluate how it meets their initial goals, and determine what changes they may want to make if they decide to adopt it.

Within the limited faculty perspective literature, most research studies were done from a postimplementation perspective and do not compare faculty experiences from an institutional perspective (e.g., Lopatto *et al.*, 2014; Wolkow *et al.*, 2014; Shortlidge *et al.*, 2016; Craig, 2017; Roberts *et al.*, 2019). Additionally, this research captured the faculty experience at a single point in time. Usually faculty CURE research was conducted through surveys or interviews with participants after they had taught a CURE at least once. Although Gené-Bacon *et al.* (2020) conducted interviews before faculty taught the CURE, it was also an investigation at a single time point. Retrospective or prospective studies capture the CURE faculty members' perception at one time point. However, it is important to consider how faculty members' perspectives change during the process of implementing a CURE. All CURE faculty studies aggregated results from a variety of institutional types, except Spell *et al*., who disaggregated their data by institution type. They found there were differences in the importance of barriers by institution type including: lack of equipment was less important at liberal arts colleges, the time needed to develop new research was less important at comprehensive and research universities, class size and number of sections was of less importance at liberal arts colleges and comprehensive universities, and student preparation was of less concern at liberal arts colleges. They also compared minority-serving (MSI) and White-majority institutions and found several differences between them. Lack of prep support, administration support, facilities, equipment, time, and effect of student evaluations were more important at MSIs than at White-majority institutions. Faculty at public institutions found lack of equipment, student preparation, and number of lab sections more important than at private institutions. These results indicate that institution type can provide different challenges for faculty teaching CUREs, but there has been no other comparison of other faculty experiences between institution types.

Using a network CURE, this study investigates the experiences of faculty from four different institutions at multiple time points in the process of adopting a CURE in order to compare the anticipated and actual experiences of faculty who implement a CURE for the first time. Additionally, this study will provide a comparison of the faculty experiences at four different institution types: a small women's MSI; a small liberal arts college; a medium-size doctoral university; and a large community college.

TABLE 1. Description of institutions and faculty participants in a network CURE

Institution	CURE faculty participants	Carnegie classification	Number of students
Private College	Jennifer, Linda, Karen	Bachelor's	1500
MSI University	Mary	Master's	1400
Master's University	Sandra, David	Doctoral	11,000
Community College	Lisa, James	Associate's	31,000

Research Questions (RQ)

1. What are faculty experiences during the implementation of a network CURE curriculum?
2. How do faculty's anticipated and actualized experiences compare?
3. How do the faculty in four institutions experience CURE implementation?

METHODS

Tigriopus CURE Context

The *Tigriopus* CURE was developed using the five elements of a CURE (Auchincloss *et al.*, 2014) along with supplemental instruction from the lecture content (see Fisher *et al.*, 2018 for a full description of the CURE and teaching materials). It is focused on answering basic questions about the copepod *Tigriopus californicus*. Teams of four students spend the first 6 weeks of this laboratory course learning basic skills needed to study copepods while developing a research question and proposal. The rest of the semester is spent investigating their research questions and presenting their results. Students in the *Tigriopus* CURE have shown improved attitudinal and learning outcomes (Olimpo *et al.*, 2016). While not a large national CURE, as implemented in this study with a team of experienced faculty and grant support, the *Tigriopus* CURE is a network CURE.

Grant-Provided Supports

This project was supported by a National Science Foundation (NSF) grant. Grant staff members included three faculty and one graduate student. CURE faculty participants were provided 4 days of face-to-face PD during the summer before they began teaching the *Tigriopus* CURE. The PD explored active learning, CURE pedagogy, how to grow and maintain the organism *T. californicus*, literature on *T. californicus*, and technical expertise for research with this organism. Monthly virtual meetings between the grant staff and faculty participants were conducted during the academic year. Additionally, the grant staff members were available for questions via email or phone. Financially, the grant provided a stipend for the faculty to collect student data, travel to the PD, and buy any equipment needed to do research with *T. californicus*.

Authors' Involvement in *Tigriopus* CURE

S.E.D.-P. was not involved in the development of the CURE, but was involved in the characterization of student outcomes during the development of the *Tigropus* CURE (Olimpo *et al.*, 2016). She was a co–principal investigator (co-PI) on the NSF grant that funded this research. She was involved in the development and implementation of the summer PD, but did not participate in the follow-up meetings. S.E.D.-P. developed the interview protocols for all three interviews and conducted the interviews. N.L.S. was not involved in the development of the *Tigriopus* CURE or PD of faculty teaching the CURE. She joined the project postimplementation.

Participants

Participants in this study include higher education faculty from four institutions who were recruited to implement the network *Tigriopus* CURE (Table 1). Names of institutions and participants were changed to preserve their anonymity.

Private College. Private College is a small, private, residential college of about 1500 students. Biology is the second-largest major, with nine faculty in the biology department. Three faculty members participated in the PD. Jennifer is a cell and molecular biologist with 14 years of teaching experience. Linda is a neuroscientist with 10 years teaching experience. Karen is an ecologist with 3½ years of teaching experience. All three taught this laboratory course previous to teaching the CURE and attended the summer PD. There was a fourth faculty member who also taught the CURE but was not present at the PD and did not participate in this research project.

MSI University. MSI University has the smallest science department in this study sample, with Mary being one of three biology faculty in the science department. MSI University is a private women's MSI with an undergraduate population of <1400 students who commute to campus. Mary was a behavioral ecologist and had 20 years of teaching experience at three different institutions. She previously taught the course and attended the summer PD.

Master's University. Master's University is a private university of about 11,000 students, 40% of whom are PEER students, with about one-third residing on campus. Biology is the largest major on campus. The biology department at Master's University is the only one in this study with a graduate program (master's degree). There are about 20 full- and part-time biology faculty in the department. Master's University faculty did not receive the summer PD, as they were added to the grant research after the summer PD occurred. However, the faculty had access to the grant staff for help in setting up and teaching the CURE. The CURE was taught by a mixture of faculty and graduate teaching assistants. Two faculty consented to be interviewed. Sandra is a biology education researcher with 8 years of academic teaching experience and an additional 4 years of environmental education and outreach. David is a behavioral ecologist with 12 years of teaching experience. Both taught the course previously.

Community College. Community College is a community college with a student population of about 31,000. Approximately two-thirds of the students are either dually enrolled high school students or basic skills–workforce development students. The students are spread across multiple campuses, community locations, and online instruction. These commuter campuses contain a student population that is 67% White and under 20 years of age. There are about 50 full- and part-time biology faculty members spread across three campuses. Lisa had 6 years of laboratory teaching experience, but did not teach lecture courses. She had work experience in the medical field, but her graduate work was in ecology. Lisa implemented the CURE in a new introductory course on biology structure and function. She attended the summer PD. During the fourth week of the CURE semester, Lisa took a different position, and James took over teaching the CURE. James is an ecologist with 9 years teaching experience and did not participate in the summer PD.

Interview Protocol

Eight faculty members were asked to consent to interviews about their expectations and experiences in implementing the *Tigriopus* CURE. Between one and three faculty at each institution were interviewed, which represented up to 100% of the faculty who taught the CURE at each institution. Interview questions were developed with Roger's (2003) *Diffusion of Innovations* as a theoretical foundation and from prior literature as part of a larger study of the decision-making process in CURE adoption. Participants were interviewed by telephone and recorded before the PD (pre-PD), after their first completion of the semester-long *Tigriopus* CURE course (postimplementation), and after teaching the CURE a second semester (postadoption; Table 2). The pre-PD interview questions focused on participants' background, teaching experiences, research experiences, knowledge of student-centered teaching practices, decision processes based on Roger's framework, and expectations for summer PD (pre-PD interview questions are provided in the Supplemental Material). The postimplementation interview focused on the participants' teaching experience in the CURE and decision processes based on Roger's framework (postimplementation interview questions are provided in the Supplemental Material). Postadoption interviews were conducted after interviewees had taught the CURE at least twice and focused on experiences teaching the CURE, decision processes based on Roger's framework, and curricular changes (postadoption interview questions are provided in the Supplemental Material). Questions for the postadoption interview were also informed by themes that emerged from the pre-PD and postimplementation interview analysis. For the participants who joined the project after the summer PD (Sandra and David from Master's University and James from Community College), retrospective interviews were conducted. For retrospective interviews, questions from the prior interview protocols were added and posed from a retrospective perspective. At Private University, Jennifer and Karen were interviewed at all three time points, but Linda was on extended leave the second time the CURE was taught and so did not participate in the postadoption interview (Table 2). At MSI University, Mary died unexpectedly after teaching the CURE; therefore, the postadoption interview was not conducted (Table 2). At Community College, James declined to be interviewed at the postadoption interview. Interviews were transcribed and analyzed in NVivo v. 12.

Analysis

Initial coding was undertaken after the first two sets of interviews were finished (pre-PD and postimplementation; Table 2). Three predetermined categories from the literature that informed the questions were 1) benefits, 2) challenges, and 3) resources in implementing the CURE. With this literature base in mind, two coders (S.E.D.-P. and N.L.S.) read through several interviews and developed possible codes from the data that described the experience of implementing the *Tigriopus* CURE. Then the coders met to discuss those codes and refine them. A coding unit was a set of text that contained one idea. Each interview could have multiple instances of each code. This process was completed iteratively until all 10 interviews were coded. Codes were grouped into themes in a hierarchical manner, developing a codebook (Creswell, 2002, 2007; Creswell and Plano Clark, 2011). Codes from at least two institutions were required to establish a theme. A fourth category about feelings emerged from the data as distinct from the other three categories. After the postadoption interviews were completed, the coders applied the codebook to the new interviews and looked for any new codes. This process was again done iteratively until coding saturation was reached (Creswell, 2002; Codebook, Supplemental Table S1). At this point, both coders rested the data for 3 months (Mackey and Gass, 2016) and then began a final coding of all interview transcripts using the coding book previously developed. After two interviews were coded by each coder, interrater reliability was determined, any inconsistencies were discussed, and the coding was decided. This process was repeated until the coders reached an interrater reliability of $\kappa > 0.8$. The rest of the interviews were then divided between the two coders and coded individually. Any questions that arose while coding those interviews were discussed between the coders, and coding was decided. As a final validity check, a draft of the results was sent to each participant, with the exceptions of Lisa (new contact information was not available) and Mary (who was deceased), to ensure clear representation of what they said about teaching the CURE.

TABLE 2. Faculty interviewed at each time point

Institution	Pre-PD	Postimplementation	Postadoption
Private College	Jennifer, Linda, Karen	Jennifer, Linda, Karen	Jennifer, Karen
MSI University	Mary	Mary	
Master's University			Sandra,* David*
Community College	Lisa	James*	
Number of interviews	5	5	4

*Retrospective interviews.

TABLE 3. Themes in the four categories associated with faculty experiences in adoption of a network CURE

Category (% of total codes)	Example participant quote
Themes	
Resources (31%) Institutional support Group support Grant resources	"To be able to compare notes across lab sections and be able to say, "Oh I'm having this problem, are you having this problem?," and so within our own [Private College] bubble, having instructors and being able to communicate, I think was the most regular support that was actually really useful for troubleshooting."—Linda, Private College, Postimplementation
Benefits (29%) Students Student–faculty interactions Faculty science identity	"I perceive that the CURE lab helps students with many of those other skills that actually [*sic*] employers care about like teamwork and problem-solving."—Sandra, Master's University, Postadoption
Challenges (26%) Students Implementation	"I had to let go. A lot … I have like three labs that I adore, and I didn't do them this semester because we were doing the CURE."—Mary, MSI University, Postimplementation
Feelings (14%) Positive Negative	"It was fun and challenging … The first time through, I felt uneasy the entire time."—David, Master's University, Postadoption

Once the interviews had been completely coded, comparisons for RQ2 and RQ3 were completed using cross tabulation in NVivo v. 12. For RQ2, time-point cross tabulation between the pre-PD and postimplementation (not postadoption) was completed for each subtheme (or theme, if there were no subthemes). This represents five interviews at each time point (Table 2). Master's University was not included in the time-point analysis, as those interviews were done as retrospective interviews at one time point, postadoption. For RQ3, cross tabulation between institutions and each subtheme (or theme, if there were no subthemes) was completed. Additionally, any codes specific for only that institution were noted (Supplemental Table S2). All institutions were included in the RQ3 analysis.

RESULTS

RQ1: What Are Faculty Experiences during the Implementation of a Network CURE Curriculum?

Several major categories resulted from the analysis of the interviews: benefits, resources, challenges, and feelings (Table 3). In each category, there are a number of themes which sometimes contain subthemes. Quotes are provided as examples of these themes and are attributed.

Category 1: Resources. Three resources themes emerged during interviews: 1A, institutional support; 1B, group support; and 1C, grant support (Table 3). These themes were mentioned by all faculty and coded 195 times in all the interviews.

Theme 1A: Institutional Support. All faculty indicated that there was strong support at their institution, college, and/or department for implementing the CURE. However, half of the faculty indicated that not everyone was supportive of implementing a CURE. Supportive and unsupportive behaviors often occurred at different institutional levels.

> "My institution is apparently quite unusual in that they are always delighted for you to implement new things, even if we're not sure if it's going to work. Because they're willing to let us explore those things."—Mary, MSI University, Postimplementation

> "I know the [lecture faculty member] was plainly frustrated that he didn't feel like any of this was relevant."—James, Community College, Postimplementation

Theme 1B: Group Support. Group support for the faculty implementing the CURE was designed into the process both during the initial summer PD and then afterward through regular online meetings between grant personnel and all the faculty teaching the CURE. However, most faculty felt that internal group support within their departments was the best type of group support and the external group support was less helpful. Six of the eight faculty mentioned group support in their interviews.

> "I think we felt different enough just because of different timing and different audience of students and logistics of setup that communicating with others at other schools didn't feel as useful."—Jennifer, Private College, Postimplementation

> "For the people that we have to interact with who are actually doing a lab, it's really, really helpful to have such a supportive group who is willing to be reflective about their experiences and work together to come up with ways to improve the experience."—Sandra, Master's University, Postadoption

Theme 1C: Grant Resources. Resources provided by the grant or grant personnel were mentioned by all faculty as important contributors to being able to implement the CURE. The grant supplied the faculty with PD in the implementation of the CURE curriculum, financial support for supplies and equipment, the curriculum, and expertise to solve problems as they arose. Common problems included growing and maintaining the algae needed to feed the *T. californicus*.

> "And obviously the financial piece to get the equipment that we needed also was really helpful; it was a really low risk investment for us to try it and once we tried it, there's no question that we're going to keep it."—Linda, Private College, Postimplementation

Even for the institution that did not start until after the PD (Master's University), the grant supplied the curriculum and expertise to help the faculty implement the CURE.

> "Having [grant staff] available as sort of like troubleshooting was invaluable. So it felt like we weren't just going it alone, we could build on other people's experiences … where other people had done the heavy lift of getting it going, and then being able to touch base with people. That was the best stuff … Having a manual that was already written was helpful … So that was probably the biggest help that we did not have to develop the whole thing from the start."—Sandra, Master's University, Postadoption

Category 2: Benefits. The benefits category was mentioned 179 times across all interviews and by every participant. The three benefit themes were: 2A, benefits for students; 2B, interactions between students and faculty; and 2C, increases in faculty science identity (Table 3).

Theme 2A: Benefits to Students. The potential or actual benefits to the students were the most commonly mentioned and discussed theme of the CURE. Faculty mentioned benefits related to three main areas of student improvement: attitudinal, learning, and 21st-century skills.

All faculty thought that students learning "real science" was very important. They articulated a number of science process skills and learning outcomes, including collaboration, iteration, technical skills, data analysis, statistical fluency, discovery, "messiness of science," literature review, asking questions, hypothesis testing, experimental design, and technical writing.

> "Hopefully our students will have a better understanding of how science works. I hope they will come out with some improved data analysis skills."—Jennifer, Private College, Pre-PD

Seven of the faculty indicated that students also benefited from changes to their attitudes and motivations for science. Faculty indicated students were more confident and engaged with the material and displayed feelings of ownership and increased science identity.

> "It was a great benefit in certain aspects of what I've seen in my students. I was seeing them become incredibly comfortable about being in the lab. I found they were excited about stuff; they were willing to work outside of class; they engaged in the process more deeply than they can in the more traditional lab format."—Mary, MSI University, Postimplementation

Six of the faculty indicated that their students developed 21st-century skills that went beyond specific science-related learning, including problem solving, curiosity, interpersonal dynamics, creativity, critical thinking, and science literacy.

> "So I think that the CURE models and shifting that focus slightly helps students in the long run learn how to gather knowledge and information and utilize that to think for themselves, to solve problems, to be innovative, to be creative, to come up with, 'Okay we know this, but what about this? Did we ever think about this?' It gives them the capacity to think outside of just pre-established knowledge and skills … massages and stimulates the mind, to work independently."—Lisa, Community College, Pre-PD

Theme 2B: Student–Faculty Interactions. Five out of the eight faculty members indicated that teaching the CURE changed the character of their interactions with students. Faculty mentioned changes such as deeper scientific conversations, more vulnerability, and empathetic conversations with their students.

> "I think it [the CURE] has shifted what I get to focus on with students. So rather than focusing on 'Did you follow all of the steps in the right order?,' I get to focus on 'Hey, did you think about this interesting thing? And with this thing, how would you go about controlling for that?' I get to talk to them like, 'Oh, you're interested in the effects of DEET about copepods? Why? What's out there about this that's relevant?'"—Sandra, Master's University, Postadoption

Theme 2C: Faculty Science Identity. Three of the eight faculty indicated that teaching this CURE had revitalized their own science identity.

> "It's fun to get out of your box and to do science and to solve new problems and think about new things and studying biological systems is why I got involved in biology to begin with, so it's fun to get back and to reconnect with that process of inquiry and you know, learning something new and knowing something we didn't know before, maybe knowing something that nobody else knows. Because you're asking certain questions and you know, I felt like that was really fun for me."—James, Community College, Postimplementation

Category 3: Challenges. Challenges in teaching and implementing a CURE were coded 160 times in all interviews and discussed by every participant. Challenges fell into two themes: 3A, those that dealt with students; and 3B, those that had to do specifically with faculty implementation concerns (Table 3).

Theme 3A: Student Challenges. All eight faculty mentioned challenges with students and student work in teaching the CURE. Five faculty mentioned challenges in student resistance to the work, time, and difference of doing a CURE lab. Three faculty reported concerns about student preparedness before coming to the lab class as well as a lack of student preparation from prior learning experience that supported their ability to learn from the CURE. Four faculty felt that the proposal process was challenging for students and faculty to manage. Six faculty expressed concerns about student group work.

> "As much as this is uncomfortable for you, and you're going to want to do all the work by yourself and then come to me later and say, 'I should get the A because nobody helped,' you have to be able to delegate and you have to be able to rely on your group and you have to be able to work together. So as much as that causes problems, I think that that's a good thing in a CURE lab. I still have to find a way to navigate those problems."—David, Master's University, Postadoption

Theme 3B: Challenges in Implementation. For all faculty, teaching a CURE was a new experience, and none had any background in the organism, which led to uncertainty about their ability to teach the CURE. Six of the faculty expressed concerns about the time it would take to prepare and teach the CURE. There was also concern expressed by six faculty about the lack of connection to the corresponding lecture course material and having to "let go" of their favorite parts of their prior lab. *Tigriopus californicus* was a new organism and research area for all faculty; five faculty reported challenges working with this organism. Two faculty were concerned with the grading group work in the CURE.

> "I would say one potential drawback would be that some lab material we have, for instance right now in our 100 level majors' class does reinforce lecture material well. And so losing the opportunity to have them explore some ideas through hands-on activities."—Linda, Private College, Pre-PD

Category 4: Feelings about Teaching a CURE. There were two themes in the feelings category: 4A, positive; and 4B, negative.

Theme 4A: Positive. Faculty overwhelmingly reported positive feelings (67 mentions by all eight faculty) regarding teaching the CURE (Table 3). Faculty used adjectives such as "liking," "happy," "comfortable," "capable," "fun," "great," "thankful," "engaging," "enjoying," "enthusiastic," "excited," "confident," "interesting," "positive," "loved," "energized," "worthwhile," and "brain candy" to describe teaching the CURE.

> "It's actually a lot more fun to teach because I don't feel like I'm cracking the whip at them."—Jennifer, Private College, Postadoption

Theme 4B: Negative. There were also negative feelings associated with teaching the CURE, with six of eight faculty (21 mentions) describing negative feelings. These included, "frustrating," "worried," "hard sell," "taxing," "not great," "challenging," "hassle," "uneasy," and "struggle."

> "It was kind of this open inquiry model of asking any question you want, the individualized nature of that was I think a component … that I found intriguing, albeit it makes things kind of a hassle."—James, Community College, Postimplementation

RQ2: How Do Faculty's Anticipated and Actualized Experiences Compare?

Some of the faculty experiences, as described in postimplementation interviews, deviated from expectations described in the pre-PD interviews, while some of the experiences were fundamentally the same as they expected.

Category 1: Resources. Group support was mostly anticipated by the faculty to be provided by the grant group who were at the PD and involved in teaching the CUREs. There were regular grant group virtual meetings held throughout the implementation of the CURE. However, after teaching the CURE, most participants indicated that within-institution group support was a key component of the resources available for teaching the CURE (Figure 2). Faculty who were the only person teaching the CURE at their institutions indicated that they mostly determined answers to their own challenges for themselves. For both situations, group or single faculty, internal support was prioritized, because faculty felt that the circumstances of their own institutions were unique and best answered from within that community. Institutional support was almost uniformly described as supportive during the pre-PD interviews. High levels of support from colleagues, departments, and colleges were also reported after teaching the CURE. However, several specific instances of nonsupportive behaviors and conversations were reported after teaching the CURE (Figure 2). After implementation, the types of financial resources and the PD fulfilled faculty expectations expressed before the PD. After implementation, faculty reported the support of the grant personnel in solving specific problems with teaching the CURE to be extremely helpful. However, before the PD, they had not anticipated that they would need to use this resource (Figure 2).

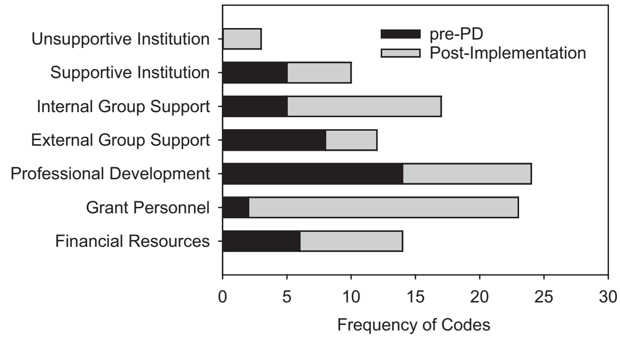

FIGURE 2. Changes in resources by time point. This is a comparison of the total number of codes in the resources category, coded before implementation (pre-PD) and after implementation (postimplementation), for faculty from Private College, MSI University, and Community College.

Category 2: Benefits. Student learning outcomes were stressed before and after implementation of the CURE (Figure 3). Faculty wanted students to learn science process skills and reported that their students had learned these important skills after completing the CURE. After teaching the CURE, students attitudinal benefits were stressed by faculty more often. Students' confidence and independence in working in the lab were attitudinal benefits only reported by faculty after teaching the CURE. While several 21st-century skills were anticipated by faculty, especially problem solving, learning teamwork was not a stated learning outcome for any of the faculty before teaching the

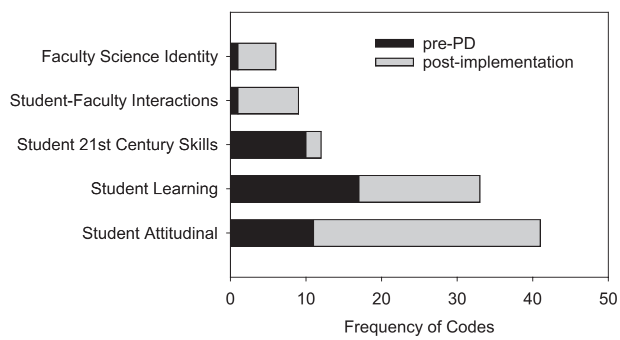

FIGURE 3. Changes in benefits by time point. This is a comparison of the total number of codes in the benefits category, coded before implementation (pre-PD) and after implementation (postimplementation), for faculty from Private College, MSI University, and Community College.

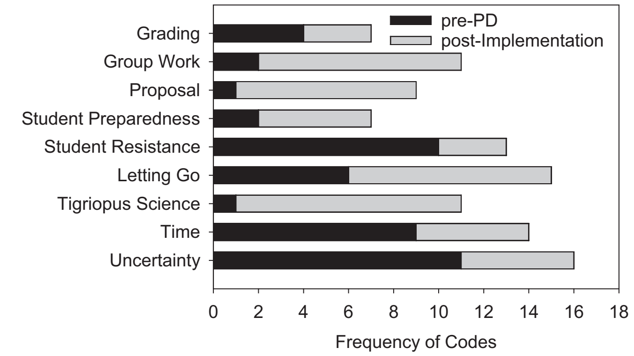

FIGURE 4. Changes in challenges by time point. This is a comparison of the total number of codes in the challenges category, coded before implementation (pre-PD) and after implementation (postimplementation), for faculty from Private College, MSI University, and Community College.

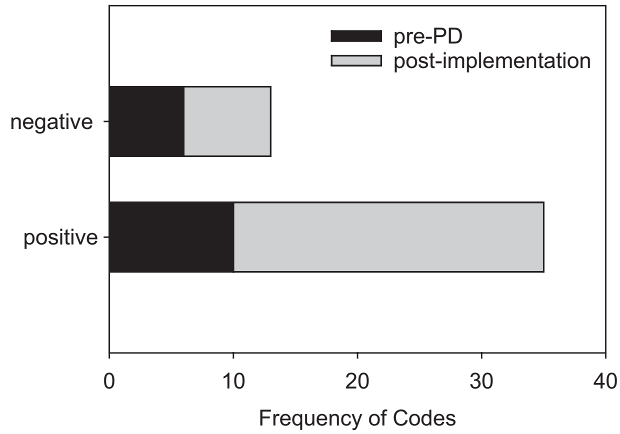

FIGURE 5. Changes in feelings by time point. This is a comparison of the total number of codes in the feelings category, coded before implementation (pre-PD) and after implementation (postimplementation), for faculty from Private College, MSI University, and Community College.

CURE. However, learning teamwork was mentioned by three of the faculty in the postimplementation interviews, and problem solving was not mentioned at all. Benefits not anticipated by the faculty included the positive impacts on their own science identity and the changes in their interactions with students. Only one participant, Linda, anticipated these possible benefits, while three faculty included descriptions of impacts to their own science identity, and four discussed improved faculty–student interactions.

Category 3: Challenges. Faculty were concerned about student resistance to learning through research before the PD, but they reported very little student resistance to learning through research after teaching the CURE (Figure 4). One faculty member was concerned about student preparation, but did not express that as a challenge after teaching the CURE. Two other faculty did report instances with student groups who were not prepared to engage with the material in any depth. Group work and preparation of the research proposal were mentioned by two faculty members before they taught the CURE. After the CURE, four of the faculty described in detail problems that students had with group work and developing a research proposal (Figure 4). The time it would take to assess student work was the concern before teaching the CURE. After teaching the CURE, were mostly related to individual versus group assessments (Figure 4).

Not surprisingly, faculty expressed more uncertainty about teaching the CURE before participating in the PD than they discussed after they had taught the CURE (Figure 4). In postimplementation interviews, uncertainty was expressed retrospectively rather than related to future *Tigriopus* CURE courses. A major concern before teaching the CURE was related to the time it would take to prepare and teach a new course. Afterward, there were only two mentions of time and preparation constraints. Instead, the major time constraint indicated after teaching the CURE had to do with "budgeting time well for students in every lab" (Karen, Private College, Postimplementation). Letting go of their favorite labs was a concern expressed more after teaching the CURE. The least anticipated issue was problems that faculty had with the science of *T. californicus*. There were unanticipated technical problems with growing the algae that *Tigriopus* eats and working with *Tigriopus* that required faculty to learn new skills. A lack of familiarity with the literature base was expressed both before and after teaching the CURE. Learning these new skills and the literature base was a challenge, but contributed to improved science identity for several faculty (Figure 4).

Category 4: Feelings. While positive feelings about the *Tigriopus* CURE were expressed more than negative ones, they were expressed at even higher levels after teaching the CURE (Figure 5). Negative feelings, however, were expressed about equally before and after teaching the CURE. Not surprisingly, the predominant positive emotion before the CURE was excitement and anticipation, while the predominant negative emotion was concern. After teaching the CURE, the predominant positive feelings were comfort, confidence, and fun, while negative feelings were usually expressed as frustration and struggle.

RQ3: How Do the Faculty in Four Institutions Experience CURE Implementation?

The four institutions in this study differed by size, student composition, residential status, classification, and number of faculty participating (Table 1). Additionally, there were several disruptions to the faculty makeup of this study, including the replacement of a faculty member during the initial semester of instruction (Community College), the death of a faculty member after the initial semester of instruction (MSI University), and the addition of an institution after the PD (Master's University). All of these instances complicated data collection and research design, but are important within a study of faculty experiences. These are all examples of real-world complications that can occur any time a new curriculum is implemented, and including these considerations improves the resulting data. Despite the considerable difference between the institutions, 39% of the themes/subthemes are coded for every institution (see Supplemental Tables S3–S6). In this section, we will consider those that differed and include codes that were important to the faculty at individual institutions, but not coded to a subtheme because they were not seen across two or more institutions.

Private College. Of the four institutions in this study, Private College's reliance on internal group support was the strongest. The three faculty felt that working out solutions to their problems happened best in their group of faculty rather than through external networks (see "Resources" quote, Table 3). Additionally, they found the opportunity to collaborate with their peers an advantage to teaching this CURE.

> "I was able to spend some time working closer with my colleagues to develop new labs and active learning strategies and that was positive on building relationships with my peers."—Karen, Private College, Postimplementation

Private College was the only institution where neutral institutional support was mentioned. Their department chair was part of the team teaching the CURE, which gave very strong departmental support.

> "Our administration just kind of said, 'Go ahead.' They didn't impede us, but … I wouldn't say they really supported us. That being said, [name] is part of our group of CURE collaborators and she is department chair so obviously she is very supportive, but administration didn't seem to notice or care."—Karen, Private College, Postimplementation

Student engagement, project ownership, and learning real science were the most important student benefits faculty anticipated that were realized. Private College was one of the two institutions whose faculty discussed the positive impacts of teaching the CURE on their own science identity. The faculty at Private College were only slightly concerned about letting go of their old lab, and that concern was completely related to the lack of congruity between lecture and lab content. Two student challenges were rarely mentioned by the faculty at Private College: student preparedness and group work. Faculty were not concerned about group work before the PD, and it was only mentioned twice in the postimplementation interviews. Student preparedness was only mentioned once in the postimplementation interviews.

MSI University. Mary was an expert in organismal biology and found it exciting to get to teach a CURE that was organismal rather than molecular based. She was confident before the PD that she could teach this CURE because of her background and understanding of CUREs. She saw doing a CURE in the introductory biology course as an extension of what she was already doing in the lab and as preparation for the required capstone research course. While research output was not a requirement of her position, faculty were required to mentor undergraduate student research. Mary did not mention either benefits for herself in student–faculty interactions or science identity. This might be due to the high level of scientific inquiry already present in the former lab, which included several inquiry modules that spanned multiple lab sessions (data not shown) and the amount of research mentoring required by her position. She was not concerned about student resistance, proposal writing, or grading. Her unique challenges occurred because of the nature of a very small department. Different lab classes were run in the same room during the day, so space, time, equipment, and facilities were a challenge.

> "I need to know perhaps, if I'm doing a CURE lab in the morning, what's the best way I can switch over to a micro lab in the afternoon in the same classroom … because there's definitely going to be the same classroom for micro, developmental biology, and this CURE … that's going to be a lot going on in one room."—Mary, MSI University, Pre-PD

As the only CURE faculty member at her university, she had no internal group support and did not find the external group support useful. However, she had technical problems with maintaining *T. californicus*, which required extensive grant personnel support to solve. She found "letting go" of some of her favorite labs from her prior curriculum very difficult, discussing this before and after implementing the CURE (see "Challenges" quote, Table 3).

Master's University. Changes in student–faculty interactions were important at Master's University.

> "In the traditional lab, like, if they were doing, like, the eye experiment … I kind of knew what would happen … and they could say, 'Well, is this right?' And I would have to not say yes or no, even though I knew what the answer was, and kind of say, 'Well, what do you think the data says?' Here, if they were to say, 'Well is this the right thing?,' I would have to say, 'Well there is no right or wrong, the data is what the data is. How did you design the experiment? I can only answer your question by asking you a question.' And eventually get them to the point of saying, 'Oh, you know, it's not really black and white.'"—David, Master's University, Postadoption

For Master's University, the student benefits emphasized were the students learning real science, student engagement, and 21st-century skills. Interestingly, the only implementation challenge code reported by Master's University was uncertainty, and they had the highest levels of reported uncertainty, which might be because they did not participate in the PD. Master's University was the only institution that reported challenges in the tension between research and teaching, which might be related to being the only institution with a graduate program in the study.

> "What if the department decides not to adopt this? Then I don't know how much effort to put into it."—David, Master's University, Postadoption

> "It's part of my duties to update things for the Spring. Which is fine, but I don't have tenure yet, so this is not high on my priority list. I get way more credit for publishing something than I do for updating a lab manual."—Sandra, Master's University, Postadoption

Master's University reported student resistance and group work as their only student challenges. Not surprisingly, grant-related support was reported less by Master's University than the other institutions, as Master's was not supported financially by the grant and did not receive PD. Still, they reported that having an already developed curriculum and someone to call on when they had questions were important features of this CURE curriculum. There was more contention reported at Master's University than at the other institutions. While there was support for the CURE, they also reported the highest level of "resistant" faculty.

> "The people who were not actively contributing to the lab, ehhh. They aren't super excited about it."—Sandra, Master's University, Postadoption

Community College

> "I basically took the class over on a Wednesday and the next class meeting was on a Monday… so we did a very short transition and then she was gone and not available as a resource."—James, Community College, Postimplementation

This abrupt change in instruction midsemester was most likely why the most negative feelings about teaching the CURE were expressed by James. While Lisa had attended the PD, James had not. When he took over the class, the students had already designed their projects. This was frustrating for him.

> "I had a lot of feedback for them … [but] they had already kind of started pouring their efforts into those projects."—James, Community College, Postimplementation

However, even with this situation, James repeatedly described how much fun he found in teaching the CURE, expressing more overall positive feelings than negative. Community College was one of the two institutions where faculty expressed increases in their science identity from teaching the CURE. James liked learning about a new organism, new research techniques, and brushing up on techniques he had not used in a long time. Lisa and James both emphasized the student benefit of learning real science.

> "The focus is not so much that I want you to come out of this understanding photosynthesis and how it works; I want you to understand how using experimentation can lead you to draw and develop conclusions about concepts…. That's the focus of what we're doing, is what's less understanding the concepts, and more about understanding how to gather data and evidence to formulate valid conclusions."—Lisa, Community College, Pre-PD

Interestingly, since the CURE was taught in a newly developed course, James discussed "letting go" as a challenge more than faculty at any other college or university. He found that he had to change what he expected was possible for the students in one semester, and allow them to fail. Also, the lack of connection between the CURE and lecture content was a concern for the faculty member who taught the lecture. James plans on working more closely with the lecture faculty member moving forward. Student preparedness and group work were the two biggest student challenges for Community College, with more concern expressed by Lisa and James on these challenges than at any institution in this study. James was one of the three faculty who had group grading concerns.

> "There was some pretty serious griping and discussion about grades … and the contributions of the other group members."—James, Community College, Postimplementation

A unique challenge for Community College was the limited number of hours that faculty members could require for student engagement in a one-credit class. Institutionally, a 3-hour lab left little time outside the lab for homework; the amount of time outside the lab required by the CURE exceeded those limits.

> "So we're trying to work through [the time limit] as an institution, but I just threw that out for this class because it wasn't going to work."—James, Community College, Postimplementation

DISCUSSION AND CONCLUSIONS

The goals for this study were to elucidate the faculty experience during the implementation and adoption of a network CURE. In this section, we discuss the impacts of using a longitudinal approach to examine the faculty experiences. We highlight unique findings from this research. We also consider possible limitations to this study. We finish with some suggestions for CURE PD and future research.

Perceptions of CURE Implementation Depend on Time and Context

An inconsistent finding in previous research studies pertained to institutional support, with some network CUREs reporting nonsupportive behaviors (Lopatto *et al.*, 2014; Craig, 2017), while other CURE developer studies described supportive behaviors (Spell *et al.*, 2014; Shortlidge *et al.*, 2016). This study highlights that the time at which the interviews take place as well as institutional context may account for supportive or nonsupportive behaviors experienced when implementing a network CURE. None of the faculty described a lack of support from colleagues, departments, or institutions before implementing the CURE. However, there were nonsupportive behaviors reported in three of the four institutions after teaching the CURE, which is more consistent with prior network CURE research that was conducted postimplementation (Lopatto *et al.*, 2014; Craig, 2017). The flavor of the unsupportive comments was relatively mild, "not every one of my colleagues was on board with it, but you know that's how faculty are" (Sandra, Master's University, Postadoption), rather than a consistently unsupportive attitude. Additionally, there may be support at one level of the institution and not at another (e.g., Private College had departmental support, but lack of interest at higher levels). In this study, the departments/colleges were often part of the initial contact and introduction to the CURE, which might have biased this sample toward more institutional support than previously reported for network CUREs.

As in the few studies that have highlighted benefits of teaching CUREs (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017; Genné-Bacon *et al.*, 2020), we found that faculty concentrated on student benefits, especially before teaching the CURE. However, the faculty seemed to be unaware of the difference in anticipated versus unanticipated student benefits. The differences came through in the data, with a greater emphasis on 21st-century skills before teaching the CURE, but a heavier emphasis on student engagement and motivation after teaching the CURE. Student learning was equally emphasized before and after teaching the CURE. This seems to indicate that the benefits faculty wanted for the students were relatively general. The student benefits they encountered were then seen as meeting their initial goals.

Challenges to teaching a CURE are the most commonly studied aspect of the faculty experience and we found many of the same challenges, including student preparation (Lopatto *et al.*, 2014; Spell *et al.*, 2014), student resistance (Shortlidge *et al.*, 2016; Roberts *et al.*, 2019; Govindan *et al.*, 2020), difficulty with learning new literature/skills (Lopatto *et al.*, 2014; Roberts *et al.*, 2019), and time (Lopatto *et al.*, 2014; Spell *et al.*, 2014; Goedhart and McLaughlin, 2015; Hensel and Cejda, 2015; Shortlidge *et al.*, 2016; Govindan *et al.*, 2020). However, anticipated challenges and actual challenges were different, highlighting the importance of longitudinal studies. For example, time is a commonly reported challenge: relating to time in the class (Lopatto *et al.*, 2014; Spell *et al.*, 2014), planning (Goedhart and McLaughlin, 2015; Shortlidge *et al.*, 2016), developing a CURE (Shortlidge *et al.*, 2016), and workload (Hensel and Cejda, 2015; Govindan *et al.*, 2020). Pre-PD faculty expressed concern that time to prepare and teach a new CURE was going to be a challenge. But after teaching the CURE, the concern for time had to do with the students: the time in class and time to finish their projects.

As found by Shortlidge *et al.* (2016, 2017) and included in representative quotes (Craig, 2017), this study also highlights the "fun" of teaching a CURE for faculty. While there were negative emotions, positive emotions were reported more often, especially after teaching the CURE. The negative emotions before the CURE were mostly concern, while afterward there was some frustration. However, faculty were excited before the CURE, and there was a broad sense of enjoyment after they had implemented the CURE. They enjoyed interacting with students around something that they were passionate about (research).

While prior research has highlighted several benefits for faculty teaching a network CURE (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2016, 2017), there were two themes of mostly unanticipated benefits for faculty in this study: positive interactions with students and impacts to their own science identity. As reported by Shortlidge *et al.* (2016, 2017), faculty in this study found their interactions with students in the classroom to be more in depth and scientifically richer. Faculty also described impacts on their own science identity, reinforcing their identity as a scientist as well as an instructor. Interestingly, the impacts to their own science identity were more commonly mentioned by faculty at institutions without a significant research component (Supplemental Table S4). In a study with both network CUREs and CURE developers, Shortlidge *et al.* (2017) reported that faculty found teaching a CURE matched their science identity, but the data were not disaggregated by type of CURE. With their study of CURE developers only, Shortlidge *et al.* (2016) did not report any consequences for faculty science identity. This suggests that faculty without a strong research component to their positions find that teaching a CURE is also an opportunity to "do science" (James, Postimplementation, Community College), thus impacting their identity as a scientist. These unanticipated benefits for themselves seemed to be considered a bonus of teaching the CURE for these faculty.

Consistent with other network CURE research, the resources from the grant for PD, supplies, curriculum, and equipment were considered important by the faculty in the study (Lopatto *et al.*, 2014; Craig, 2017). Having the grant staff available to answer questions about working with *Tigriopus* was highly valuable for all of the participants. Faculty did not anticipate the need they would have for support from the grant personnel, but reported that support as important postimplementation. Even for Master's University faculty, who did not attend the PD or have financial support, it was important that they could implement the CURE without the large time investment that developing their own CURE would take. In two other network CUREs, Craig (2017) found that faculty were frustrated because the protocols were not ready on time, and Wolkow *et al.* (2014) found increased PD needed for community college faculty. Similar to Lopatto *et al.* (2014), faculty in this project, including Lisa and James (Community College), were uniformly positive about the help provided by the grant resources including the curricular materials. Like the Genomics Education Project (the CURE explored in Lopatto *et al.*, 2014), the *Tigriopus* CURE had been successfully implemented for several years before this project (Olimpo *et al.*, 2016; Fisher *et al.*, 2018), giving the grant personnel lots of experience, well-developed curricular materials, and expertise in teaching this CURE. This emphasizes the importance of a well-developed curriculum and expertise with the CURE for the successful implementation of a network CURE.

Unique Challenges and Benefits

A unique finding was the faculty emphasis on students developing 21st-century skills. Prior research indicated development of skills transferable to future careers as a student benefit that faculty valued (Lopatto *et al.*, 2014; Shortlidge *et al.*, 2017), but this idea related to the development of technical and science process skills that will help students in future jobs (which were included in student learning in our codebook). Faculty in this study considered the development of generally transferable job skills such as teamwork, problem solving, critical thinking, creativity, and learning how to learn to be benefits of a CURE. These are skills that are highly valued by employers of STEM students (Saunders and Zuzel, 2010; Sarkar *et al.*, 2016). While faculty mentioned these outcomes more during the pre-PD interview, the types of transferable skills discussed were consistent between the pre-PD and postimplementation interviews, indicating the faculty perceived that the students had learned them.

Two unique CURE implementation challenges from this study were uncertainty and letting go. Uncertainty was primarily expressed pre-PD compared with interviews done postimplementation. Uncertainty may be higher for network CURE faculty, because they are usually teaching a new research system rather than incorporating a research system with which they are intimately familiar. Letting go of the continuity between laboratory and lecture and not teaching some laboratory modules from the prior course were a problem for some of these faculty. The lack of continuity between lecture and lab was also a concern for the *Tigriopus* CURE developer (Fisher *et al.*, 2018), so each laboratory period started with supplemental instruction using active-learning strategies related to a known difficult concept from that week's lecture. This may have highlighted the difference in content between the lecture and lab for the faculty. The loss of material covered is a common concern of implementing active learning (Guy, 2017; Shadle *et al.*, 2017) that seems to translate to the replacement of a laboratory course with a CURE.

Some unique student challenges in this study include proposals and group work. Group work and proposal writing were major challenges of teaching the CURE that were not highly anticipated. While collaboration is usually integrated into a CURE (Auchincloss *et al.*, 2014), the *Tigriopus* CURE relies heavily on students working in productive groups. Additionally, because this was in introductory biology, for most students these skills (group work and proposal writing) were new experiences.

In Craig (2017), a faculty member was concerned the CURE would not be sustainable if there was only one faculty member involved. As demonstrated by this study, long-term adoption of a CURE can hinge on a single faculty member. The removal of the pivotal faculty member (by death, job change, etc.) can completely stop or drastically change the adoption process. In two of our four institutions, this happened. The death of Mary (MSI University) resulted in the institution ending their participation in this study, despite her highly favorable feelings and plans to continue teaching the CURE. At Community College, the abrupt departure of Lisa left James teaching a new curriculum that he eventually stopped teaching in favor of becoming a CURE developer (personal communication). The two institutions that continued teaching the *Tigriopus* CURE were those with internal group support and multiple faculty teaching the CURE, which provided stability despite some changes in personnel throughout the study period.

Support for Adoption of New Teaching Strategies Hypotheses

Understanding the faculty perspective in adoption of CUREs can also be applied to the adoption of active-learning strategies in general. Andrew and Lemons (2015) proposed several hypotheses about the adoption of new teaching strategies developed from their research on case study teaching. While this study was developed before their publication and not intended to test their hypothesis, it provides support for two of their hypotheses from a very different teaching context. Hypothesis 3 stated: "Perceptions of improved student outcomes facilitate sustained use of active-learning strategies" (Andrews and Lemons, 2015, p. 14). The most coded subtheme in this study was benefits to students. While there was a specific interview question about the benefits of a CURE, student benefits were regularly coded outside the context of that question. Faculty in this study described perceived student benefits as the most important reason for continuing to use a CURE. Like Andrews and Lemons, even though these faculty reported student resistance, they concentrated on the positive student outcomes they saw. CUREs provide faculty extended periods of time to interact with students, thus providing many opportunities to observe student learning and engagement with the materials. Hypothesis 4 stated: "Viewing colleagues as resources for teaching will facilitate sustained and effective active-learning instruction" (Andrews and Lemons, 2015, p. 15). Internal group support was highly valued within Private College. The faculty described multiple instances of turning to one another for help in solving problems while teaching the CURE and plans for changes in future iterations of the CURE. While internal group support was not as strongly supported in Master's University, the faculty there also reported its impact in implementing the CURE. Despite trying to develop an external support system, the faculty in this study turned to well-known colleagues as resources for teaching the CURE instead. Only the institutions with multiple faculty sustained teaching this CURE in this study.

PD for CUREs

While not specifically a study of PD for the *Tigriopus* CURE, several suggestions did arise from the data. The PD was designed using best practices for PD from the K–12 teacher PD, including: activities to learn active-learning frameworks that support CUREs; practice with the organisms and skills needed to successfully do research with *T. californicus*; introduction to the literature base on this organism; dedicated time to develop CURE-related activities wherein institutions with similar concerns were grouped together and multiple faculty from the same institution attended together where possible; virtual follow-up after the summer in-person PD; and support resources, including the exercises and literature (Loucks-Horsely *et al.*, 2003; Burke and Hutchins, 2007; Desimone, 2009).

Since the development of the *Tigriopus* PD, several suggestions for postsecondary faculty PD have been proposed that include many of the strategies from the K–12 teacher PD literature (e.g., D'Avanzo, 2013; Khatri *et al.*, 2016; Manduca, 2017; Beck and Blumer, 2019). Not surprisingly, the *Tigriopus* PD mostly followed the suggestions put forth by these authors. Beck and Blumer (2019) recently proposed five recommendations specifically for laboratory instruction PD: 1) attendance in teams; 2) curricular development that requires little work after the PD; 3) time to work on products from the PD that include hands-on activities; 4) sufficient time for learning, but not too long for busy faculty; and 5) ongoing support systems.

There are several specific content items that network PD should explicitly address. For network CURE PD, explicitly addressing the immediate uncertainties, while important, needs to be balanced with the challenges of teaching a CURE. Especially if student groups are used in an introductory CURE, explicit PD around student group work is needed (e.g., forming, storming, norming, and performing from Tuckman, 1965). Time management within the laboratory setting is a critical element of a successful CURE. Specific suggestions from the curriculum developers about where time can be spent and what can be done outside class is important. To do this, the network CURE developers need to be very conversant with the CURE. Additionally, curriculum and teaching materials that support faculty in teaching proposal development and writing should be important parts of network PD. For network CUREs, addressing the potential negative emotions should be done during the initial PD and during the initial implementation semester. It helps people to realize that others share their feelings—that what they are feeling is normal. This could be especially important for newer faculty who have little experience in implementing a very different curriculum and for very experienced faculty who may have forgotten the nerves that accompany teaching something new.

Interestingly, although continued community is a best practice for PD (Loucks-Horsely *et al.*, 2003; Desimone, 2009; Beck and Blumer, 2019) and considered important by faculty in other network CUREs (Lopatto *et al.*, 2014; Craig, 2017), only internal (vs. external) group support was important to the faculty in this study. Even the two institutions with a single participant did not find the external group support to be important. This could be related to the type of community support provided or the composition of the faculty who were involved in this CURE. The initial development of a community relied heavily on the face-to-face PD, which was then followed up with virtual meetings. Mary (MSI University) was a very experienced instructor and confident of her abilities to teach the CURE even before attending the PD. James (Community College) and Master's University faculty had no opportunity to develop initial relationships with the other faculty because they did not participate in the PD. While Private University faculty were at the PD, they relied on their tight-knit internal community for support. Those faculty who were part of a community showed a reliance on each other and the grant personnel, but not on faculty members from other institutions. Our data also suggest that attending in teams and having ongoing support systems are important in network CURE PD.

Limitations

Limitations of this study include the nature of the interview sample. There were 17 interviews over a 2-year period of time with eight people in the study and one to three people representing each institution. Due to real-life circumstances, not all of the participants were interviewed at all three time points. Sandra and David from Master's University and James from Community College were each interviewed once after teaching the CURE. The same questions were asked as those before the PD, but in a retrospective manner (Table 2). This might have affected how the participants responded, because their current experiences may have influenced answers about their experiences before teaching the CURE. For this reason, Master's University data were not used in the time-point analysis. However, given the real-life nature of sudden changes in instructional faculty, Lisa (pre-PD) and James (postimplementation) from Community College were included in the time-point analysis, because those interviews were taken at specific time points within a single institution. While there were definite differences in the experiences of the faculty at each institution, those experiences may be only the experiences of the faculty in this study and may not be generalizable to faculty in other institutions of the same type. Additionally, S.E.D.-P. was a co-PI on this grant and participated in the development and implementation of the Fall 2016 and Summer 2017 PD. This might have biased the interview question development; however, the grant evaluator was consulted about the interview question development.

During analysis of the postadoption interviews (Fall 2019), both researchers were involved in a new CURE. Faculty member S.E.D.-P. was teaching a new network CURE course, while student N.L.S. was taking the same CURE course. This may have changed the emphasis during coding due to the inevitable feelings of kinship expressed by participants as a result of the benefits and challenges of this study. In early 2020, with the codebook established, the intent was to go through the data once more to make sure everything was coded completely. Due to the COVID-19 pandemic, there was a pause of approximately 3 months during the data analysis process. While inadvertent, this rest time improved the data analysis. We approached the data from a fresh perspective that clarified coding descriptions, refined organization, and allowed us to better disengage our own experiences with the phenomenon (Mackey and Gass, 2016). We notice that resting the data is not a commonly reported method in qualitative biology education research and suggest that other researchers include this methodology in their future qualitative analyses.

Future Research

This study highlights the different experiences of faculty throughout the implementation and adoption of a CURE. Therefore, future research should carefully consider where in the CURE adoption process the faculty member is as an explanation for the results. The short and long-term consequences for faculty, not just students, are important contexts to study. Especially of interest is the differences in benefits to faculty from network CUREs and CURE developers. Is there a difference in the identities of these faculty that impacts what benefits accrue to them? This study also highlights the need to explore the role of community and internal versus external support in network CUREs. Research on the impacts of inter- versus intracommunity support networks and multiple versus single innovators would improve our understanding of what supports are needed for long-term adoption of network CUREs. Probing the communication networks used by faculty during the adoption process would also contribute to understanding the support networks used by faculty during the CURE implementation process.

While there is more research on student impacts, this study also emphasizes some new areas for future researchers to explore in student outcomes. Currently, CURE student outcomes research relies heavily on student self-reported outcomes, specific content learning, and attitudinal measures (NASEM, 2017). Measures of 21st-century skills development could also be included for student outcomes from CUREs. This would be especially helpful for CURE researchers who are studying multiple CUREs that do not share similar content. Given that group work was a challenge for all faculty in this study regardless of prior experience, we also suggest that the student research group dynamics need to be studied to determine the best way to teach both research skills, and group research skills.

This study highlights the importance of a longitudinal and institutional lens to contribute to the understanding of the faculty experience in teaching a network CURE. As shown through interviews with the faculty at these four institutions, the anticipated and experienced challenges and benefits of teaching a CURE are not the same. In recruiting faculty to teach CUREs, we suggest that the benefits to faculty, as well as students, be emphasized (Shortlidge *et al.*, 2016, 2017). However, because the initial anticipated benefits were student-centric, those should be put forward as the major benefits. While challenges to implementing a CURE are well established, there has been limited focus on benefits to the faculty teaching the CURE. This study contributes to our understanding of both anticipated and perceived benefits from CUREs for faculty and students. We found faculty perceive that development of 21st-century skills for students is important. We found enhanced science identity, sense of enjoyment, and improved interactions with students as benefits for faculty.

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REFERENCES

Andrews, T. C., & Lemons, P. P. (2015). It's personal: Biology instructors prioritize personal evidence over empirical evidence in teaching decisions. *CBE—Life Sciences Education*, *14*(1), ar7. https://doi.org/10.1187/cbe.14-05-0084

Asai, D. (2020). Excluded. *Journal of Microbiology & Biology Education*, *21*(2). https://doi.org/10.1128/jmbe.v21i1.2071

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

Bangera, G., & Brownell, S. E. (2014). Course-based undergraduate research experiences can make scientific research more inclusive. *CBE—Life Sciences Education*, *13*(4), 602–606. https://doi.org/10.1187/cbe.14-06-0099

Beck, C. W., & Blumer, L. S. (2019). A model for an intensive hands-on faculty development workshop to foster change in laboratory teaching. *Journal of Microbiology & Biology Education*, *20*(3). https://doi.org/10.1128/jmbe.v20i3.1799

Burke, L. A., & Hutchins, H. M. (2007). Training transfer: An integrative literature review. *Human Resource Development Review*, *6*(3), 263–296. https://doi.org/10.1177/1534484307303035

Carter, F. D., Mandell, M., & Maton, K. I. (2009). The influence of on-campus, academic year undergraduate research on STEM Ph.D. outcomes: Evidence from the Meyerhoff Scholarship Program. *Educational Evaluation and Policy Analysis*, *31*(4), 441–462. https://doi.org/10.3102/0162373709348584

Chang, M. J., Sharkness, J., Hurtado, S., & Newman, C. B. (2014). What matters in college for retaining aspiring scientists and engineers from underrepresented racial groups. *Journal of Research in Science Teaching*, *51*(5), 555–580. https://doi.org/10.1002/tea.21146

Corwin, L. A., Graham, M. J., & Dolan, E. L. (2015). Modeling course-based undergraduate research experiences: An agenda for future research and evaluation. *CBE—Life Sciences Education*, *14*(1), es1. https://doi.org/10.1187/cbe.14-10-0167

Craig, P. A. (2017). A survey on faculty perspectives on the transition to a biochemistry course-based undergraduate research experience laboratory. *Biochemistry and Molecular Biology Education*, *45*(5), 426–436. https://doi.org/10.1002/bmb.21060

Creswell, J. W. (2002). *Educational research: Planning, conducting, and evaluating quantitative and qualitative research*. Upper Saddle River, NJ: Merrill Prentice Hall.

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks: Sage.

Creswell, J. W., & Plano Clark, V. L. (2011). *Designing and conducting mixed methods research*. Los Angeles, CA: Sage.

D'Avanzo, C. (2013). Post–*Vision and Change*: Do we know how to change? *CBE—Life Sciences Education*, *12*(3), 373–382. https://doi.org/10.1187/cbe.13-01-0010

Desimone, L. M. (2009). Improving impact studies of teacher's professional development: Toward better conceptualizations and measures. *Educational Researcher*, *38*(3), 181–199. https://doi.org/10.3102/0013189X08331140

Espinosa, L. (2011). Pipelines and pathways: Women of color in undergraduate STEM majors and the college experiences that contribute to persistence. *Harvard Educational Review*, *81*(2), 209–241. https://doi.org/10.17763/haer.81.2.92315ww157656k3u

Estrada, M., Hernandez, P. R., & Schultz, P. W. (2018). A longitudinal study of how quality mentorship and research experience integrate underrepresented minorities into STEM careers. *CBE—Life Sciences Education*, *17*(1), ar9. https://doi.org/10.1187/cbe.17-04-0066

Fechheimer, M., Webber, K., & Kleiber, P. B. (2011). How well do undergraduate research programs promote engagement and success of students? *CBE—Life Sciences Education*, *10*(2), 156–163. https://doi.org/10.1187/cbe.10-10-0130

Fisher, G. R., Olimpo, J. T., McCabe, T. M., & Pevey, R. S. (2018). The *Tigriopus* CURE—A course-based undergraduate research experience with concomitant supplemental instruction. *Journal of Microbiology & Biology Education*, *19*(1). https://doi.org/10.1128/jmbe.v19i1.1503

Genné-Bacon, E. A., Wilks, J., & Bascom-Slack, C. (2020). Uncovering factors influencing instructors' decision process when considering implementation of a course-based research experience. *CBE—Life Sciences Education*, *19*(2), ar13. https://doi.org/10.1187/cbe.19-10-0208

Gin, L. E., Rowland, A. A., Steinwand, B., Bruno, J., & Corwin, L. A. (2018). Students who fail to achieve predefined research goals may still experience many positive outcomes as a result of CURE participation. *CBE—Life Sciences Education*, *17*(4), ar57. https://doi.org/10.1187/cbe.18-03-0036

Goedhart, C. M., & McLaughlin, J. S. (2015). Overcoming the barrier to implementing authentic research experiences through faculty mentorship. *CBE—Life Sciences Education*, *14*(2), le1. https://doi.org/10.1187/cbe.15-01-0007

Govindan, B., Pickett, S., & Riggs, B. (2020). Fear of the CURE: A beginner's guide to overcoming barriers in creating a course-based undergraduate research experience. *Journal of Microbiology & Biology Education*, *21*(2). https://doi.org/10.1128/jmbe.v21i2.2109

Guy, B. R. (2017). Movers, shakers, & everyone in between: Faculty personas surrounding active learning in the undergraduate STEM classroom. *i.e.: inquiry in education*, *9*(2), ar6. Retrieved September 16, 2022, from https://digitalcommons.nl.edu/ie/vol9/iss2/6

Hanauer, D. I., Graham, M. J., Betancur, L., Bobrownicki, A., Cresawn, S. G., Garlena, R. A., ... & Russell, D. A. (2017). An inclusive research education community (iREC): Impact of the SEA-PHAGES program on research outcomes and student learning. *Proceedings of the National Academy of Sciences USA*, *114*(51), 13531–13536. https://doi.org//10.1073/pnas.1718188115

Harrison, M., Dunbar, D., Ratmansky, L., Boyd, K., & Lopatto, D. (2011). Classroom-based science research at the introductory level: Changes in career choices and attitude. *CBE—Life Sciences Education*, *10*(3), 279–286. https://doi.org/10.1187/cbe.10-12-0151

Hensel, N. H., & Cejda, B. D. (2015). Embedding undergraduate research in the community college curriculum. *Peer Review*, *17*(4), 27–30. https://doi.org/10.2139/ssrn.1997675

Hernandez, P. R., Woodcock, A., Estrada, M., & Schultz, P. W. (2018). Undergraduate research experiences broaden diversity in the scientific workforce. *BioScience*, *68*(3), 204–211. https://doi.org/10.1093/biosci/bix163

Jones, M. T., Barlow, A. E., & Villarejo, M. (2010). Importance of undergraduate research for minority persistence and achievement in biology. *Journal of Higher Education*, *81*(1), 82–115. https://doi.org/10.1353/jhe.0.0082

Khatri, R., Henderson, C., Cole, R., Froyd, J. E., Friedrichsen, D., & Stanford, C. (2016). Designing for sustained adoption: A model of developing educational innovations for successful propagation. *Physical Review Physics Education Research*, *12*(1), 010112. https://doi.org/10.1103/PhysRevPhysEducRes.12.010112

Linn, M. C., Palmer, E., Baranger, A., Gerard, E., & Stone, E. (2015). Undergraduate research experiences:: Impacts and opportunities. *Science*, 347(6222), 1261757. http://dx.doi.org/10.1126/science.1261757

Lopatto, D., Hauser, C., Jones, C. J., Paetkau, D., Chandrasekaran, V., Dunbar, D., ... & Barnard, D. (2014). A central support system can facilitate implementation and sustainability of a classroom-based undergraduate research experience (CURE) in genomics. *CBE—Life Sciences Education*, *13*(4), 711–723. https://doi.org/10.1187/cbe.13-10-0200

Loucks-Horsely, S., Love, N., Stiles, K., Mundry, S., & Hewson, P. W. (2003). *Designing professional development for teachers of science and mathematics*. Thousand Oaks, CA: Corwin Press.

Mackey, A., & Gass, S. M. (2016). *Second language research: Methodology and design*. New York: Routledge.

Manduca, C. A. (2017). Surveying the landscape of professional development research: Suggestions for new perspectives in design and research. *Journal of Geoscience Education*, *65*(4), 416–422. https://doi.org/10.5408/17-281.1

McDonald, K. K., Martin, A. R., Watters, C. P., & Landerholm, T. E. (2019). A faculty development model for transforming a department's laboratory curriculum with course-based undergraduate research experiences. *Journal of College Science Teaching*, *48*(3), 14–23. https://doi.org/10.2505/4/jcst19_048_03_14

Nagda, B. A., Gregerman, S. R., Jonides, J., von Hippel, W., & Lerner, J. S. (1998). Undergraduate student-faculty research partnerships affect student retention. *Review of Higher Education*, *22*(1), 55–72. https://doi.org/10.1353/rhe.1998.0016

National Academies of Sciences, Engineering, and Medicine (NASEM). (2015). *Integrating discovery-based research into the undergraduate curriculum: Report of a convocation*. Washington, DC: National Academies Press. https://doi.org/10.17226/21851

NASEM. (2017). *Undergraduate research experiences for STEM students: Successes, challenges, and opportunities*. Washington, DC: National Academies Press. https://doi.org/10.17226/24622

Olimpo, J., DeChenne-Peters, S. E., & Fisher, G. R. (2016). Development and evaluation of the *Tigriopus* course-based undergraduate research experience: Impacts on students' content knowledge, attitudes, and motivation in a majors introductory biology course. *CBE—Life Sciences Education*, *15*(4), ar72. https://doi.org/10.1187/cbe.15-11-0228

Roberts, R., Hall, B., Daubner, C., Goodman, A., Pikaart, M., Sikora, A., & Craig, P. (2019). Flexible implementation of the BASIL CURE. *Biochemistry and Molecular Biology Education*, *47*(5), 498–505. https://doi.org/10.1002/bmb.21287

Rodenbusch, S. E., Hernandez, P. R., Simmons, S. L., & Dolan, E. L. (2016). Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. *CBE—Life Sciences Education*, *15*(2), ar20. https://doi.org/10.1187/cbe.16-03-0117

Rogers, E. M. (2003). *The diffusion of innovations*. New York: Free Press.

Russell, S. H., Hancock, M. P., & McCullough, J. (2007). Benefits of undergraduate research experiences. *Science*, *316*(5824), 548–549. https://doi.org/10.1126/science.1140384

Sadler, T. D., & McKinney, L. (2010). Scientific research for undergraduate students: A review of the literature. *Journal of College Science Teaching*, *39*(5), 43–49.

Sarkar, M., Overton, T., Thompson, C., & Rayner, G. (2016). Graduate employability: Views of recent science graduates and employers. *International Journal of Innovation in Science and Mathematics Education*, *24*(3), 31–48.

Saunders, V., & Zuzel, K. (2010). Evaluating employability skills: Employer and student perceptions. *Bioscience Education*, *15*(1), 1–15. https://doi.org/10.3108/beej.15.2

Shadle, S. E., Marker, A., & Earl, B. (2017). Faculty drivers and barriers: Laying the groundwork for undergraduate STEM education reform in academic departments. *International Journal of STEM Education*, *4*(1), 8. https://doi.org/10.1186/s40594-017-0062-7

Shapiro, C., Moberg-Parker, J., Toma, S., Ayon, C., Zimmerman, H., Roth-Johnson, E. A., … & Sanders, E. R. (2015). Comparing the impact of course-based and apprentice-based research experiences in a life science laboratory curriculum. *Journal of Microbiology & Biology Education*, *16*(2). http://dx.doi.org/10.1128/jmbe.v16i2.1045

Shortlidge, E. E., Bangera, G., & Brownell, S. E. (2016). Faculty perspectives on developing and teaching course-based undergraduate research experiences. *BioScience*, *66*(1), 54–62. https://doi.org/10.1093/biosci/biv167

Shortlidge, E. E., Bangera, G., & Brownell, S. E. (2017). Each to their own CURE: Faculty who teach course-based undergraduate research experiences report why you too should teach a CURE. *Journal of Microbiology & Biology Education*, *18*(2). https://doi.org/10.1128/jmbe.v18i2.1260

Shuster, M. I., Curtiss, J., Wright, T. F., Champion, C., Sharifi, M., & Bosland, J. (2019). Implementing and evaluating a course-based undergraduate research experience (CURE) at a Hispanic-serving institution. *Interdisciplinary Journal of Problem-Based Learning*, *13*(2). https://doi.org/10.7771/1541-5015.1806

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

Tuckman, B. W. (1965). Developmental sequence in small groups. *Psychological Bulletin*, *63*(6), 384–399. https://doi.org/10.1037/h0022100

Wei, C. A., & Woodin, T. (2011). Undergraduate research experiences in biology: Alternatives to the apprenticeship model. *CBE—Life Sciences Education*, *10*(2), 123–131. https://doi.org/10.1187/cbe.11-03-0028

Wolkow, T. D., Durrenberger, L. T., Maynard, M. A., Harrall, K. K., & Hines, L. M. (2014). A comprehensive faculty, staff, and student training program enhances student perceptions of a course-based research experience at a two-year institution. *CBE—Life Sciences Education*, *13*(4), 724–737. https://doi.org/10.1187/cbe.14-03-0056