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SMART CUREs: a Professional Development Program for Advancing Teaching Assistant Preparedness To Facilitate Course-Based Undergraduate Research Experiences

Amie M. Kern[a] and Jeffrey T. Olimpo[a]

[a]Department of Biological Sciences, The University of Texas at El Paso, El Paso, Texas, USA

Course-based undergraduate research experiences (CUREs) have emerged as a viable platform to engage large numbers of students in real-world scientific practices. Historically, CUREs have been offered throughout science, technology, engineering, and mathematics curricula at both the introductory and advanced levels and have been facilitated by a variety of individuals, including faculty members, postdoctoral fellows, and graduate teaching assistants (GTAs). This latter population, in particular, has increasingly been tasked with facilitating CUREs, yet they often receive little meaningful professional development to improve pedagogical skills vital to this type of instruction. To address this disparity, we designed and evaluated a semester-long intervention to support GTAs ($N = 7$) responsible for leading CUREs at our institution during the Fall 2020 semester. Intervention activities included synchronous interactive discussions, reflective journaling, and asynchronous practical exercises. Analysis of retrospective postintervention survey responses and focus group interview data revealed that participants exhibited gains in their understanding of the dimensions of CUREs, strategies for mentoring undergraduates, and use of various pedagogical techniques as well as confidence in addressing and adopting those dimensions and strategies in their courses. Furthermore, participants reported finding value in the sense of community created through the intervention, which served as a means to share ideas and struggles throughout the term.

KEYWORDS course-based undergraduate research experience, CURE, biology, biochemistry, teaching assistant, TA, laboratory, professional development

INTRODUCTION

CUREs as an instructional model for undergraduate biology laboratory education

National efforts to reform science, technology, engineering, and mathematics (STEM) laboratory curricula have historically emphasized the importance of integrating authentic research practices into the learning environment, as these "real-world" opportunities have been shown to have a significant impact on students' personal and professional growth (1, 2). Within the last decade, course-based undergraduate research experiences (CUREs) have been posited to be an inclusive mechanism to meet this need (3). Numerous studies have highlighted the positive influence of biology CUREs on student attitudes, researcher self-efficacy, science identity development, and experimental design competency (4–7). Faculty who facilitate CUREs have likewise reported benefits with respect to increasing direct interaction with students, connecting research and teaching goals, and recruiting students to their research laboratories (8).

Broadly speaking, CUREs are a type of laboratory course in which students address a research question or problem that is of interest to the wider community with an outcome that is unknown both to the students and to the instructor (9). While no singular model of a CURE exists, all CUREs share five core features, which collectively distinguish them from traditional laboratory coursework. These features include the following: (i) utilization of scientific practices, (ii) collaboration, (iii) a focus on "important work," (iv) scientific discovery, and (v) iteration (9). One of the primary functions of CUREs is to make research experiences available at scale, rather than to a select few individuals who seek out research internships or who are selected by faculty to participate in apprenticeship-style UREs (3, 9). It is important to note that, as part of this process, CURE students are viewed as legitimate participants in scientific research because their actions contribute to

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Address correspondence to Department of Biological Sciences, The University of Texas at El Paso, El Paso, Texas, USA. E-mail: jtolimpo@utep.edu.
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achievement of research goals (10). As is the case for traditional UREs, CUREs similarly engage students in relevant scientific practices through an apprenticeship-type structure that allows them to work on laboratory research projects under the direction of a faculty member (11, 12).

As stated above, students who have participated in CUREs have demonstrated academic gains similar to those exhibited by students who partake in independent research experiences (3, 5, 10). Conclusions from a growing body of literature have documented myriad positive student outcomes associated with these types of faculty-mentored research experiences, such as an understanding of disciplinary-level content knowledge and development of critical thinking skills (11, 12). Importantly, engagement in CUREs has also been identified as a positive predictor of retention in the sciences. Research conducted by Rodenbusch et al. (13) on the Freshman Research Initiative at The University of Texas at Austin revealed, for instance, that participation in CUREs increased students' likelihood of graduating with any degree within 6 years of starting the program by more than 16% relative to a matched comparison group. A synthesis study conducted by Bangera and Brownell (3) highlighted similar positive student outcomes, leading those authors to advocate that universities mandate CUREs as introductory laboratory experiences for all students. With their vast potential, CUREs may truly be the answer to the national call for widespread involvement of undergraduate students in research (3, 13, 14).

Role of instructors in CURE contexts

Due to their success, CUREs have continued to be offered throughout national STEM curricula at both the introductory and advanced levels and are facilitated by numerous individuals across diverse institutional contexts. While CURE instruction varies between universities, and between departments, it is always intended to be facilitated by a "senior researcher" (9). Faculty members, postdoctoral employees, and graduate teaching assistants (GTAs) are all deemed to be appropriate individuals to fill the position, as they are all thought of as possessing the expertise needed to execute the role in an efficient and purposeful manner (8). This leaves a wide range of individuals with varying levels of research proficiency in charge of facilitating CUREs and ensuring that they are implemented with the highest fidelity.

Effective CURE instruction may, in fact, depend on where in this spectrum of research experience an instructor falls. It can be challenging for novice researchers to facilitate CUREs, for instance, due to the dynamic and unpredictable nature of CURE learning environments (15). Numerous calls have been made for universities to mandate CUREs as introductory laboratory courses, yet the ability to implement them may be limited by the variations in instructor effectiveness alluded to here and elsewhere in the literature (3). In a larger sense, variations in the types of instructors charged with facilitating CUREs has led to speculation regarding the attributes of a successful CURE instructor. It has been suggested by Shortlidge et al. (8) that if adequate structural support for CUREs is provided, the challenges to developing and implementing CUREs may be surmountable. We contend that such action is crucial, as it is well-known that quality teaching can enhance student learning and is a key predictor of student success (16–18).

More acutely, Shortlidge et al. (8) identified seven prevalent obstacles reported by CURE instructors. These obstacles included the following: (i) time and work investment, (ii) the expanded role of the instructor, (iii) overcoming student resistance, (iv) the uncertain nature of scientific research (teaching patience through iteration), (v) lack of background in scientific research (inexperience with project design), (vi) the ability of instructors and students to deal with the unknown, and (vii) an unwillingness for instructors to invest the necessary time and effort to enhance their teaching practice. Interestingly, these findings closely align with those reported by Heim and Holt (19), who also identified seven primary challenges faced by CURE TAs, such as (i) time commitment, (ii) lack of expertise, (iii) logistics, (iv) academic unreadiness of first-year undergraduates, (v) feelings of inadequacy in serving in a supervisory capacity, (vi) motivating students to take ownership of their work, and (vii) the fact that CURE instruction requires a lot of critical thinking on the part of the TA.

CURE facilitators are often expected to make direct instructional decisions, including how information should be presented, which concepts should be emphasized, and how to evaluate student work (20). Many instructors have recounted challenges keeping track of and consulting on numerous simultaneous projects, some of which pushed the bounds of their expertise (8). Because students in CUREs are working on real research problems with unknown answers, the experiments may not always go as planned, and research projects may venture into unknown territory for both the student and the instructor (8). As such, student resistance may also be an issue, as some students may not want to be challenged to think on their own without being told what to do or given answers (8). Course observation data have further revealed that CURE instructors need to be mentors, guides, and/or counselors to students and often have more face-to-face time with students than they would typically have in a non-CURE course (19, 21). Collectively, these findings suggest that CURE instructors have a wide range of additional teaching responsibilities than those required of a traditional laboratory course. As the number of biology CUREs continues to increase and, consequently, the role of TAs in CURE facilitation continues to become more prevalent, the need for CURE TA professional development (PD) is critical. Accordingly, it is anticipated that effective TA PD will need to focus on the core features of CUREs as well as the aforementioned challenges to CURE instruction.

Toward development of effective CURE TA PD

As a wide variety of individuals, with varying levels of research and teaching experience, can be charged with instructing CUREs, it stands to reason that they may each have different PD needs (3, 8). Developing PD programs that lead to more effective instructional practices may depend on fully identifying and addressing the needs of less-experienced researchers across STEM disciplines. For example, a second-year GTA in engineering may have different needs and vastly different PD expectations than a fourth-year GTA in biology. With the larger variety of individuals being assigned to teach CURE curricula, it is essential that all individuals be trained in effective CURE instructional techniques (22). By improving GTA training and teaching ability, in particular, departments can improve CURE experiences for students and potentially offer a greater variety of CUREs across their curriculum (23).

Prior work conducted by Duran et al. (24) indicated that teacher efficacy beliefs are positively and significantly impacted by PD programs directed at pedagogical content knowledge. Professional development initiatives that include teacher training exercises have been shown to give instructors confidence, support, and feedback by allowing them to practice a small part of what they plan to do with their students among friends and peers (25). Studies have likewise shown that both science content preparation and sustained pedagogical preparation were necessary to reduce science teaching anxiety and increase science teaching efficacy (26). As national standards for what constitutes high-quality STEM instruction continue to rise, preparing effective teachers capable of engaging all students in science learning likewise continues to be imperative (27).

Previous data from our own group (28) suggested that faculty ($N = 49$) who participated in 1-day workshops centered around CURE TA PD expressed a direct need for the formation of a community to address CURE TA PD as well as a curated repository of CURE TA PD resources. Furthermore, when asked to identify topics that they believed were critical to incorporate into CURE TA PD, survey respondents indicated the following areas as being most salient: (i) strategies for improving students' ability to "think like a scientist" (~95% of respondents), (ii) strategies for helping students troubleshoot failure (~95% of respondents), (iii) strategies for teaching experimental design (~90% of respondents), (iv) assisting TAs in understanding their role as instructor (~90% of respondents), and (v) mentoring strategies (~85% of respondents). Recently (in Fall 2020), we leveraged these findings to create a virtual professional learning community intervention for TAs ($N = 7$; 88% of all eligible participants) facilitating health sciences, biology, and biochemistry CUREs at our institution. We were especially interested in examining the following research questions:

1. What impact does participation in the STEM Mentoring, Assessment, Research, and Teaching in CUREs (SMART CUREs) initiative have on GTAs' self-reported knowledge of and affect toward effective practices for facilitating CUREs?
2. What perceptions do GTAs hold regarding the utility and value of the SMART CUREs experience to their own personal and/or professional development?

Given the interactive nature of the intervention (see "Overview of the SMART CUREs program," below), we hypothesized that participants would report, at minimum, moderate gains in their knowledge of teaching practices to address the five dimensions of CUREs (9). This prediction was in alignment with previous reports in the literature (15, 29). Similarly, we anticipated that affective gains with respect to participants' confidence levels in incorporating said teaching practices would be observed, as SMART CUREs was intentionally designed to focus on "unpacking" the practical applications of those pedagogies. Finally, we expected that GTAs would hold positive perceptions of the program, as SMART CUREs is the only CURE-focused PD community on our campus and, thus, would offer the GTAs a space to connect and share ideas around effective CURE instruction.

Conceptual framework

The conceptual framework guiding this study is based on an adaptation of the basic model proposed by Desimone (30) for developing and studying effective teacher PD, to include CURE-specific teaching knowledge. This framework is especially relevant due to its ability to represent the interactive relationships between the core elements of effective CURE PD, teacher knowledge and affect, classroom practice, and how to best influence teacher and student outcomes. Although we did not explicitly focus on changes in instruction and student-level outcomes, this theory is germane because it outlines a general understanding of how to define effective CURE GTA PD practices and how to best implement learning opportunities for the maximum benefit of both instructors and students.

METHODS

Participant sampling and recruitment procedures

A mixed-methods approach was used to evaluate CURE GTA outcomes ($N = 7$; 88% of all eligible participants) in the context of a virtual professional development intervention. This intervention involved GTA instructors facilitating health sciences, biology, and biochemistry CUREs at an R1, Hispanic-serving institution in the Fall 2020 semester. These CUREs were offered in a fully online or hybrid modality due to restrictions imposed by the 2019 coronavirus disease (COVID-19) pandemic. All participants were masters and doctoral students with varied levels of teaching and research experience (see Table 1 for participant demographic information). Participants were recruited solely on the basis of having been assigned to facilitate a CURE within the last academic year, including during the Fall 2020 semester. Participants were provided a stipend ($500.00) upon completion of the program as an acknowledgment of their time and dedication.

TABLE 1
SMART CUREs participant demographics

Category	Participants (*n*)[a]
Graduate degree program[b]	
Biological Sciences	4
Chemistry and Biochemistry	2
Interdisciplinary Health Sciences	1
Prior laboratory teaching experience	
1–2 yrs	1
3–5 yrs	5
>5 yrs	1
Prior CURE teaching experience	
1–2 yrs	6
>2 yrs	1
Prior mentoring experience	
Prior experience	7
No prior experience	0
Prior undergraduate research experience	
Prior experience	4
No prior experience	3
Prior pedagogical training	
Prior training	2
No prior training	5
Prior mentor training	
Prior training	2
No prior training	5

[a]*N* = 7.
[b]Note that the degree program also reflects the broad discipline of the CURE.

Ethics statement

Approval to conduct human subjects research was obtained from The University of Texas at El Paso's Institutional Review Board (IRB) under protocol ID 1644484.

Overview of the SMART CUREs program

The primary intent in creating SMART CUREs was to contribute to the development of PD opportunities that had the capacity to provide GTAs with the necessary pedagogical skills and knowledge to effectively overcome the many reported barriers of CURE instruction (e.g., facilitating student experimentation and troubleshooting) (8, 15, 31). Our work was further informed by that of Heim and Holt (19), who identified seven primary challenges faced by CURE GTAs (e.g., lack of mentoring training), and by insights gained through our own work regarding the core tenets and effective practices for CURE TA PD, as described earlier in this article. Collectively, these and previous findings can inform best practices for developing, implementing, and evaluating CURE GTA PD opportunities in the STEM fields.

SMART CUREs activities focused on the primary areas of importance self-reported by CURE TA PD facilitators and CURE TAs (28), which were found to include the following: (i) promotion of instructors' pedagogical content knowledge, which refers to the manner in which teachers relate their pedagogical knowledge to their subject matter knowledge (31), and understanding of their instructional role; (ii) strategies for engaging students in troubleshooting failure through iterative experimentation; (iii) mentoring approaches; (iv) strategies for promoting students' experimental design competency (i.e., ability to "do" science); and (v) facilitating students' ability to think scientifically. More acutely, these areas were used as the foundation for various TA PD exercises (active learning, backward lesson plan design, etc.).

Intervention activities included alternating biweekly synchronous discussions, asynchronous practical exercises, reflective journaling, and metacognitive activities for the duration of 13 weeks during the semester. As alluded to previously, alternating synchronous and asynchronous sessions were designed to be both theoretical and practical in nature, offering a complementary approach to unpacking each of the central foci of the PD experience. Synchronous sessions were held virtually through the Zoom software platform and included presession reading(s) on the weekly topic and reflective journaling prior to the session, with posts submitted through Blackboard, as well as group activities and discussion during the session. Asynchronous sessions were designed to build upon and reinforce the face-to-face synchronous meetings.

Specifically, each synchronous virtual meeting consisted of an hour-long professional development exercise coupled with small- and large-scale group discussions intended to develop pedagogical content knowledge, instill teaching self-efficacy, foster mentoring skills, and convey evidence-based teaching practices. Interactive virtual exercises for small- and large-group dialogue included the use of the Zoom interactive whiteboard, Google Sheets brainstorming, and virtual breakout rooms to facilitate individualized and personal discussions. In addition to group discussion and forum exercises, participants were asked to develop a personalized teaching philosophy and a mentor introduction video tailored to the CURE they facilitate and were given tools to assess the effectiveness of their own CURE.

The complete schedule of SMART CUREs activities can be found in Table 2. Weekly materials can be accessed at the following link: https://tinyurl.com/smartcures.

Survey and interview procedures

To determine program effectiveness, participants were invited to first complete a retrospective, postintervention survey and, subsequently, to engage in a semistructured focus group interview. Survey questions included Likert-type item statements designed to explore GTA affect, as

TABLE 2
Overview of the SMART CUREs program

Wk	Topic[a]	Reading(s) due	Deliverable(s)
1	(Orientation to Blackboard site)		
2	Conceptions of "good" teaching	Reading set 1	
3	*Developing a teaching philosophy*	Asynchronous "lecture"	Teaching philosophy (first draft)
4	Achieving inclusion through mentorship	Reading set 2	Prompt 1
5	*Mentor video introduction*		Video
6	Experimentation in CUREs	Reading set 3	Prompt 2
7	*Reflection on experimentation, assessment*		Brief write-up or synthesis
8	Collaboration and project ownership	Reading set 4	Prompt 3
9	*Analysis of student collaboration survey data*		Reflection on survey outcomes
10	Troubleshooting and iteration	Reading set 5	Prompt 4
11	*Ethics and RCR education in CUREs*	E/RCR articles	E/RCR "Strategies" handout
12	Broader relevance, CURE-Community connection	Reading set 6	Prompt 5
13	SMART CUREs round-up and self-reflection		Focus group, postsurvey
Finals wk			Submit revised draft of teaching philosophy

[a]Note that the topics in italics represent asynchronous sessions, whereas those not italicized represent synchronous sessions. RCR, responsible conduct of research.

described previously, and were adapted from McDonald et al. (29), who evaluated a CURE faculty development model as part of their institution's curricular reform plan (see Appendix S1 in the supplemental material). Demographic items were likewise included. Semistructured focus group interviews were brief (~45 min) and were conducted using a format suggested by Kreuger et al. (32) for informative group discussions. Interview topics of interest reflected those themes present in our research questions as well as the weekly forum themes and covered the following categories of program effectiveness: (i) the overarching SMART CUREs structure, (ii) the utility of each of the weekly lessons, and (iii) GTAs' future CURE instructional plans (see Appendix S1).

Data analysis

Quantitative metrics obtained from participant Likert-item responses were entered into SPSS (v.27; IBM) for the purposes of frequency analysis. Descriptive statistics were likewise tabulated for all postintervention survey responses. Due to our limited sample size, and consequently a lack of statistical power, no inferential statistical tests were performed.

A descriptive-interpretive approach (33) was used to analyze qualitative data from this phenomenological study. Specifically, semistructured focus group interview data were subjected to content and thematic analysis to identify patterns in participant responses with respect to the three topical foci cited above. To achieve this, the raw focus group interview data were first transcribed verbatim and subsequently blinded (with pseudonyms being assigned to all participants) prior to being coded by two individuals with expertise in biology education (the authors). Strong inter-rater reliability was observed ($\kappa = 0.882$; $P < 0.001$), with all disputes being resolved via discussion between the two raters during the consensus coding phase.

RESULTS

Participation in SMART CUREs leads to increases in GTA knowledge and confidence

Descriptive analyses of GTAs' Likert-item survey responses indicated that all participants reported moderate-to-great gains in their knowledge of the core topics framing the weekly SMART CUREs sessions. Notably, these gains were most substantial in the areas of developing CURE instructional goals and identifying strategies to facilitate student collaboration, troubleshooting and iteration of experiments, and mentoring of student teams (Fig. 1).

Similar gains in GTA confidence were further reported, with participants indicating that engagement in SMART CUREs empowered them to be more reflective of their own classroom practice (Fig. 2). Conversely, GTA confidence levels were more variable with respect to reading science education literature and promoting students' development of experimentation skills. It is unclear what factor(s) led to this variability, although we posit that general lack of familiarity with the education research literature contributed to the former observation, whereas limitations imposed by transitioning CUREs to an online learning environment in response to the COVID-19 pandemic motivated the latter observation.

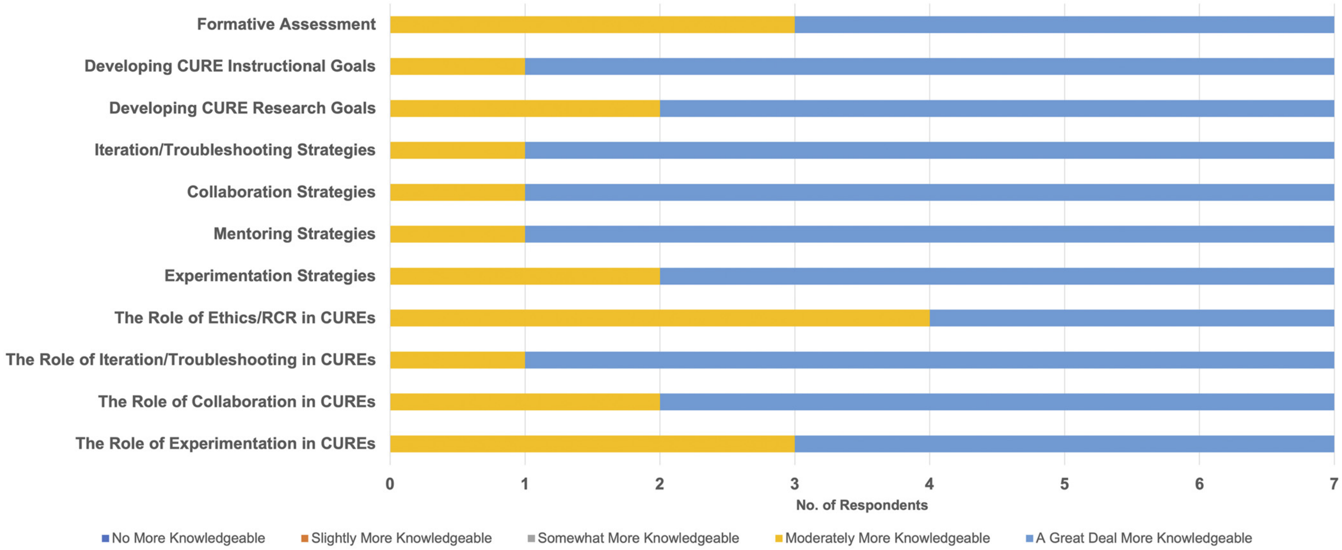

FIG 1. CURE TA's self-reported gains in knowledge with respect to the cited areas following engagement in the SMART CUREs program.

GTAs reported benefiting from community membership, idea sharing, and career exploration

Thematic analysis of focus group interview data yielded three overarching themes: (i) the importance of belonging to a community of practice, (ii) dedicated time to share ideas and strategies, and (iii) opportunities to discuss connections between CURE instruction and career and teaching praxis impacts. In what follows, we describe these themes in greater detail and offer GTA vignettes that exemplify said themes.

Belonging to a community of practice

Professional STEM education learning communities have been demonstrated to be a powerful mechanism to create a shared vision and reflective teaching practices among its constituents, thereby ameliorating some of the common challenges (e.g., lack of time, lack of relevancy) associated with PD efforts (29, 34). With specific respect to GTAs, previous studies reveal that attention to GTA PD is highly variable across institutional contexts, with one study noting that more than half of the universities and colleges surveyed in their research required biology GTAs to spend ten or fewer hours participating in teaching PD per year (35). Currently, there are limited opportunities for GTAs to engage in pedagogically-oriented PD at the institution at which this research occurred, and there are no other CURE PD experiences available aside from SMART CUREs. It is therefore perhaps unsurprising that GTAs in our study capitalized upon the benefit of

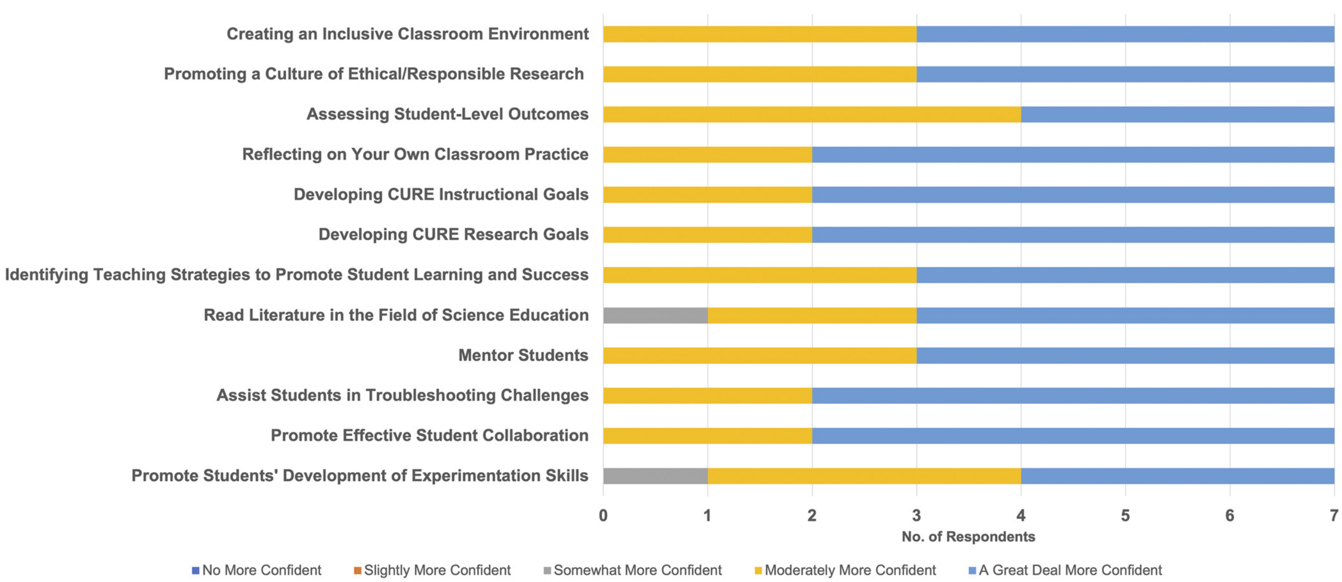

FIG 2. CURE TAs' self-reported gains in confidence with respect to the cited areas following engagement in the SMART CUREs program.

belonging to a community of practice, as stated by Penelope:

> "I hadn't participated in anything like this in the past [where] I felt like I actually got something out of it that I could actually apply to what I was doing. I found myself talking about this program to my parents and my labmates."

Maria and Carmen expanded upon Penelope's comment by describing how participation in the SMART CUREs community allowed them to address unique challenges during the Fall 2020 semester:

> ". . . my other peers that are in the [M.S./Ph.D.] program with me, they don't teach a research-driven course, so we couldn't really collaborate or share ideas so much, because those kinds of courses are structured where the instructors just give you the map, so to speak, and you do what they say, and that's it. There's no questions about it." [Maria]

> "I think it was perfect timing to have this type of collaboration – or not collaboration, but being able to talk to others about it, because we all switched to online. And I guess that that was the biggest struggle that I personally was going through, where the students – I was not aware how I was going to be able to interact with them and stuff. So, being able to talk about all of those situations and problems. . . I think that was also very helpful. And being able to just talk about it with other people, because I feel like talking about online teaching. . . is that it's very hard, and people are still trying to figure it out. And being able to figure it out with others, instead of by yourself, it's kind of comforting." [Carmen]

As evidenced by the above statements, community formation was viewed as a conduit for idea sharing which, at times, extended beyond the boundaries of the SMART CUREs network itself (as suggested by the quote from Penelope). It is this notion of idea sharing to which we turn our attention next.

Sharing of ideas and strategies

As mentioned by Maria in the preceding section, sharing ideas and strategies emerged as a common thread among all GTAs. Previous studies have shown that fostering a community of practice that allows for open communication can increase participant ownership of the work achieved as part of the community as well as make transparent that participants' contributions are valued (29). Open discussion also ensures that all community members can drive the conversation, rather than adhering to a top-down approach involving unidirectional flow of information.

With regard to teaching "tips and tools," Jasmine noted, succinctly, that:

> "I really liked how it (SMART CUREs) was all set up, honestly. I didn't know you could have different chat groups during Zoom, so I thought that was really neat, and I plan to implement that in my class."

Others, such as Graciela, acknowledged that interactions within the SMART CUREs community allowed her to recognize and adopt new strategies in her CURE to combat the transition to remote instruction:

> "There was one time, and I think it was Delphine (a SMART CUREs participant) who showed the way she was teaching. Okay, so, when I started this fall course (the CURE), and in the pandemic, and all the situation, I was finding it difficult [to figure out] how to keep my students engaged. But what I used to do is I used to take pictures and make PowerPoints and try to explain them. And then, I did not know whether they are learning, not learning, because if I ask them, they would be like, 'Yeah, go to the next level. We know what we are doing.'
>
> But then, I didn't know what to do. I met Delphine. She showed me – She showed all of us how she was making videos and uploading them to Blackboard. And that's how the students were learning from her. And that really helped me, because I started doing the same thing. And it has really helped me, and I'll continue doing the same thing in the next semester also."

More broadly, creating a space to share ideas appeared, for some, to normalize the struggle of pandemic teaching, as highlighted by the following quote from Delphine:

> "I think if I had not participated in the program, I would have been a lot more stressed out right now. I would have been a lot more scattered, trying to get in order, just trying to get – I don't know. It really helped decompress, and talk, and just bounce ideas [around] with people. Even when we just got into our little breakout groups and were discussing teaching strategies or whatever, that we usually started talking about our own personal experience, and that really helped. And [I] realized that everybody's really going through this, and it just gave me a space to just feel more, like, 'Okay, this is completely normal. This is just the pandemic, and you can handle it.'"

This latter statement, in particular, reinforces the notion that, while idea sharing in itself is a valuable practice, the direct benefits to participants with respect to teaching self-efficacy and confidence can be equally important.

Impacts on broader teaching praxis and career goals

Several of the GTAs in our study acknowledged the importance of being provided dedicated time to consider how their current role as facilitators of CUREs might intersect with their future career plans—either short term, as a GTA in subsequent semesters, or long term—and/or their teaching praxis. Nia, a biology GTA who expressed interest in teaching at a community college or primarily undergraduate institution following graduation, noted broadly that:

> "Participating in [SMART CUREs] has empowered me to feel like a better instructor; I feel that I now have a better set of tools to implement in my classroom and that I now

have more to offer my students. Even though it was just a couple of weeks, I feel like I truly benefited a lot from this."

Other GTAs, like Graciela, referenced particular aspects of the SMART CUREs program that aided her in clarifying her overarching approach to teaching and learning:

> "This course (SMART CUREs) helped me in letting me know what I actually want. For example, when I was writing [my] teaching philosophy, at that time, I got to understand what I expect or what I want out of my students. So, previously, there were things in my mind, but still, they were not on the floor or something like that. So, when I was writing [my] teaching philosophy, that's when I realized, okay, these are the things that, for example, these four things I really want to teach, and I really want my students to have by the end of the 1-year course (the CURE sequence). It (participation in SMART CUREs) was very useful for me.

This sentiment was echoed by Delphine:

> "Throughout the Ph.D. process, we've all really focused on how to develop our research skills, and our writing skills, and about how to become better scientists. We teach or try to [teach], and I haven't had any development in my teaching philosophy or any type of what I'm going to be teaching. Because usually it's handed out to me. It's like, 'Here [is the] syllabus. Here's the content. You go and just present it to the students.'
>
> But I've never had to think of myself as the teacher, and a lot of the times when you (the interviewer) were prompting us [with] questions, I was still in the student position. Like, 'Oh, okay, well, what I would do in –.' But it really helped me shift my thought perspective, and I think of myself more as a teacher. I've never even considered making a teaching philosophy, but it really helped me organize myself, and better organize the semester, and how I want to think – it really helped me to feel that. I have a strength, now, when it comes to teaching, when before it was just – hopefully I can stumble my way through this, and I'll find out, at the end, if I did it or not.

As Delphine describes, and as Schussler and colleagues (35) state, "many graduate students are encouraged to develop their skills as researchers but are rarely encouraged to develop their proficiency at teaching." Through engaging GTAs in SMART CUREs, we sought to broadly emphasize the value of this latter practice, particularly given the strong interest in teaching and teaching-oriented careers observed among the GTAs in our study and, similarly, in prior GTA PD work in the field (36, 37).

DISCUSSION

Over the last decade, the prevalence of CUREs in collegiate biology laboratory curricula has continued to grow, with numerous studies demonstrating their effectiveness at promoting students' science process skills development, positive affect, ability to "think like a scientist," and persistence in STEM (4, 6, 13, 38–41). Comparatively, little research has been conducted on the perceptions of faculty who facilitate CUREs (reference 8, for example), and even fewer studies have investigated the perceptions of GTAs tasked with leading these courses. Those that have done so have demonstrated that GTAs largely feel that they benefited from teaching CUREs with respect to their development of pedagogical and research-oriented skills. However, these same GTAs frequently reported challenges with respect to mentoring students, directing independent student research projects (which are often topically diverse), and allocating sufficient time to the CURE to ensure that it was implemented with high fidelity (19, 42). While these challenges signal a need for CURE-specific GTA PD, to the best of our knowledge, our study is among the first to describe a concerted effort to meet that need.

The SMART CUREs program was intentionally designed to integrate both theoretically- and practically-oriented exercises centered around the five core dimensions of CUREs (as described by Auchincloss et al. [9]) as well as perceived areas of importance reported by CURE faculty, staff, and GTAs (28). Given the ongoing COVID-19 pandemic, all program activities occurred virtually, although a staggered system of alternating synchronous and asynchronous sessions was employed to allow both for real-time discussion as well as independent time for GTAs to apply new knowledge to their own praxis. Our data indicated that SMART CUREs was effective at promoting GTAs' knowledge of and affect toward the majority of weekly program topics. Similarly, GTA focus group data revealed that participants appreciated the community aspect of the program, which provided them with a dedicated space to share ideas and strategies as well as reflect on their own approach to teaching. These findings are akin to the work of McDonald et al. (29), which demonstrated that faculty who participated in a summer CUREs institute found value in the collaborative nature of the PD and believed that the institute prepared them to teach their CURE curricula according to the timeline that they had developed.

We acknowledge that there are several limitations inherent of our work. Most prominently, our sample size was small, a factor derived largely from the lack of GTA rotation in teaching CUREs (i.e., the same GTA is repeatedly assigned to teach the same CURE). While such a sample size is not uncommon among previous studies on biology GTAs (42), we nevertheless caution the reader to be mindful not to overgeneralize the findings reported herein. Additionally, the entirety of the SMART CUREs program was conducted online, and while efforts were made to sustain the program into the Spring 2021 semester, this was difficult given the constant transitioning of instructional modalities due to the COVID-19 pandemic. Consequently, we strongly advocate for future research that examines both CURE GTA PD outcomes across diverse institutional contexts as well as the efficacy of various PD delivery modes, as such studies will ideally yield a more holistic representation of how to best structure CURE GTA PD to maximize both GTA and CURE student outcomes. Further, when done correctly, CURE GTA PD can ostensibly serve to mitigate some of the common challenges associated with GTA pedagogical training (e.g., failing to prepare GTAs to support student inquiry [35]), thereby empowering GTAs to be effective future educators, scholars, and leaders in the 21st-century STEM workforce (43).

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.1 MB.

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