

Faculty Perspectives on Developing and Teaching Course-Based Undergraduate Research Experiences

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National calls for the transformation of undergraduate biology education have recommended the integration of research experiences into the undergraduate curriculum. Course-based undergraduate research experiences (CUREs) have emerged as a model by which to offer research experiences to all students. Studies have demonstrated that students benefit in multiple ways from CUREs, but little is known regarding how faculty benefit. This study presents the first qualitative investigation into the perspectives of a diverse group of faculty members who have developed and taught CUREs stemming from their own research interests. The faculty participants reported a number of faculty benefits that can result from a CURE, identified a variety of challenges to implementing CUREs, and speculated about the attributes of a successful CURE instructor. Altogether, our findings could be a way to promote the widespread implementation of CUREs.

Keywords: undergraduate education, science education, faculty benefits, education reform, faculty perspectives, undergraduate research

Undergraduate research experiences in the life sciences have traditionally been achieved through apprenticed independent projects in faculty research labs. Studies on undergraduate research experiences indicate that they lead to a wide array of student benefits (Hippel et al. 1998, Seymour et al. 2004, Laursen et al. 2010, Eagan et al. 2011), but there are limited opportunities for undergraduates to participate. In response, numerous national calls have recommended integrating research experiences into the formal undergraduate curriculum, thereby giving more students the opportunity to experience research (Kenney 1998, NRC 2003, Brewer and Smith 2011, PCAST 2012, Bangera and Brownell 2014).

The emergent model for embedding research into life sciences lab courses is through course-based undergraduate research experiences (CUREs). Students who participate in CUREs have demonstrated gains similar to those obtained by students in independent research experiences. These positive outcomes include an increased interest in science and research (Lopatto et al. 2008, Harrison et al. 2011, Bascom-Slack et al. 2012, Brownell et al. 2012, Jordan et al. 2014, Rhode Ward et al. 2014), heightened self-confidence (Bascom-Slack et al. 2012, Brownell et al. 2012), enhanced conceptual understanding (Shaffer et al. 2010, Rhode Ward et al. 2014), and improved science process skills (Kloser et al. 2013, Sanders and Hirsch 2014, Brownell et al. 2015).

Similar to student experiences in traditional undergraduate research experiences, students in CUREs explore scientific

research questions with unknown answers that have relevance to the larger scientific community (Auchincloss et al. 2014, Brownell and Kloser 2015). CURE courses typically involve collaboration among students and result in students learning scientific practices through the process of doing science. CUREs differ from other lab course models (e.g., inquiry-based activities) in that they have the potential to benefit not only students but also faculty research programs (Kloser et al. 2011, Brownell and Kloser 2015).

There are currently two distinct models of CUREs: (1) an independent model in which individual faculty members develop and teach a CURE that stems from their own research interests (e.g., Brownell et al. 2012, Rhode Ward et al. 2014) and (2) a national network model in which a successful independent CURE is packaged to be taught by other faculty members, often at multiple institutions, who did not originally design the CURE (e.g., the Genomics Education Partnership, Science Education Alliances–PHAGES, and Small World Initiative). A key feature of the network CUREs is that the participating faculty are provided support to aid them in implementing the CURE (e.g., training, online forums, mentors, and a community of instructors).

National reports and funding agencies have advocated for the widespread implementation of CUREs because of the reported positive student outcomes (NRC 2003, Brewer and Smith 2011). However, faculty members who are developing and teaching these courses could also gain from the

experience, and a better understanding of their perspectives could be leveraged to promote the widespread adoption of CUREs. Identifying the factors that influence faculty members' decisions to adopt pedagogical innovations has been acknowledged as a central step in promoting reform in higher education (Blackburn and Lawrence 1995, Austin 2011, Beach et al. 2012). To date, there are few studies on the viewpoints of faculty members who are already teaching CUREs in their classrooms. One of the network CURE programs found that their instructors perceived that time, class size, and cost were the most salient barriers to teaching a CURE (Shaffer et al. 2014) but also that the central support and community provided by the program encouraged them to persist in teaching it. A related study showed that faculty members cited that the central network facilitated opportunities to help faculty publish their data from the CURE (Lopatto et al. 2014). Since many of these instructor benefits were attributed, at least in part, to the network, faculty members who are developing their own independent CUREs without this type of network may not garner those benefits. It is likely that faculty members developing and teaching their own CUREs face unique challenges, but to date, this has not been explored. We aimed to fill this gap in the literature by investigating the perspectives of a diverse group of faculty from multiple institutions that have developed and taught their own independent CUREs. Here, we focused on the following research questions: (a) What benefits do faculty who develop and teach independent CUREs gain? (b) What challenges do faculty who develop and teach independent CUREs face? (c) What attributes do faculty who have already developed and taught a CURE perceive that a colleague should possess to successfully develop and teach a CURE?

Recruitment and interviews

We conducted a national search for study participants using a convenience and snowball sampling approach that targeted life-science faculty members. We sent individual emails to approximately 100 people from more than 85 institutions who attended a national meeting on CUREs (CUREnet). We also sent emails to individuals who we believed matched our study criterion and encouraged email recipients to forward the recruitment email to colleagues. We invited individuals to participate in our study if they had developed a CURE in which (a) the course was for undergraduate credit, (b) assignments were part of the course, and (c) students conducted authentic scientific research as part of the course. We generally relied on the participant's perception of whether students conducted authentic research, but if recruited individuals requested additional information, we responded that research was considered *authentic* if neither students nor the instructor knew the outcomes to the research, which is consistent with previous definitions (Auchincloss et al. 2014).

We developed and piloted interview questions by systematically collecting iterative feedback. First, we piloted preliminary open-ended questions to two different groups

of participants in biology and/or biology education research fields ($n = 33$) and revised the questions on the basis of the responses. We then piloted the revised questions in preliminary interviews with an additional nine individuals at a national biology education meeting. From these open-ended written responses and interviews, we could determine whether the participants were interpreting the questions the way we intended them to be interpreted, and questions were modified accordingly. A final set of questions served as the guide for semistructured interviews represented in this study (supplemental appendix S1). In semistructured interviews, the interviewer follows an ordered set of questions but allows for a natural flow of conversation (Cohen and Crabtree 2006). Our final data set for this study consists of 38 participants from 31 institutions who developed and taught their own unique CUREs. Each participant was interviewed via Skype for approximately 40 minutes. Interviews were audio-recorded and transcribed (*Rev.com*, San Francisco, California). We refer to the interview study participants as *faculty*, although their official appointments may vary (supplemental appendix S2). Graduate students and postdoctoral associates were not included in this study.

Basic descriptive data were collected from the participants, including institution name, course topic, course level (introductory or upper division), gender, professional rank, peer-reviewed publications resulting from CUREs (basic science research or education research), whether they have a primarily teaching or researching position, tenure-track status, and number of years teaching a CURE. We categorized institution type using Carnegie Classifications. The Arizona State University Internal Review Board approved this study (no. STUDY00001679), and all the participants agreed for interviews to be audio-recorded and their de-identified information to be reported.

Qualitative data analysis

Participant interviews were de-identified and analyzed using the inductive approach of grounded theory, allowing for themes to arise from the text (Glaser and Strauss 1967, Strauss and Corbin 1997, Kearney 2001). The research team identified emergent themes, and a preliminary coding rubric was designed to capture those themes. To establish reliability in the rubric, interview excerpts from one-fifth of the interviews were provided with the rubric to two additional independent readers. The rubric was modified to address discrepancies in reader coding until an interrater reliability had a consensus estimate greater than 80%, calculated by dividing the number of scoring agreements by the total number of scoring decisions (Stemler 2004). One researcher then coded the remainder of the interviews, and the research team agreed on how coded statements fell into resulting thematic categories.

Identifying themes

Participants described the benefits and challenges related to developing and teaching CUREs throughout the interviews;

therefore, we chose to code the interviews in their entirety for faculty perceptions of these benefits and challenges. We also recorded the occurrences of the participants talking about having institutional or structural support for the development and implementation of their CUREs. To identify faculty perceptions of the attributes of a potentially successful CURE instructor, we coded the participant responses to the question, *If you chose a faculty member to develop and teach a CURE, what attributes would you be looking for?* Our total sample size was 38, but some of the participants did not clearly answer the question; therefore, the percentage reported is reflective of the total number who clearly answered the question (31 participants).

The categories presented in the results include coded statements made by more than 20% of the participants who answered the question; a similar cut-off has been used in other studies (Bush et al. 2015). Results for the *percentage reported* in the tables do not equal 100% because many of the participants made statements that fell into more than one theme and/or the participants made statements that did not fall into the themes represented by 20% (or more) of the participants.

Demographics of the study participants

The demographic information on each participant is located in appendix S2. This data set represents individuals from both tenure-track and nontenure-track positions, and it includes individuals from a diversity of professional ranks and positions. The participants taught CUREs in 23 upper-division and 15 introductory-level courses in life-sciences topics, including ecology, evolution, general biology, genetics, microbiology, and molecular or cellular biology. Collectively, the participants have been teaching CUREs for a mean of six years (± 0.58 SEM), with 1 year being the minimum and 16 years the maximum. Our participants' CUREs have resulted in peer-reviewed publications in both basic science and science education research. Overall, 26% of the participants had published a total of 24 science research publications from data collected in their CUREs, whereas 34% of the participants had published a total of 26 science education research publications about their CURE curriculum and/or student outcomes. Notably, three participants produced both types of publications. The mean number of CURE publications per participant was 1.32 (± 0.30 SEM).

Faculty perceptions of benefits from developing and teaching CUREs

The participants reported both faculty and student benefits resulting from CUREs. A table representing the student benefits from CUREs as perceived by the participants can be found in supplemental appendix S3. The objective of this study was to explore the impact of CUREs on faculty; therefore, we focus our study on the faculty benefits ($n = 38$; table 1). The participants reported many benefits from developing and teaching CUREs; we identified 11 themes from their interviews. All the participants stated

benefits, which were coded into more than one theme; the mean number of faculty benefit themes stated by each participant was 5.58 (± 0.30 SE). The benefits reported by faculty are outlined below.

CUREs are a way for faculty to connect teaching and research (76%). The participants discussed being able to simultaneously conduct research and teach in a CURE. The participant intentions for teaching a CURE were “twofold” or “killing two birds with one stone,” and CUREs allowed for an overlap between research and teaching.

Faculty enjoy teaching CUREs (74%). The participants stated that they enjoyed their time in the classroom more in a CURE than in a non-CURE lab course; they disliked teaching traditional “cookbook” labs but liked teaching CUREs. They indicated that as faculty teaching CUREs, they themselves were generally more interested, engaged, and excited about what happens in the CURE classroom.

CUREs can contribute positively to promotion and/or tenure (68%). The participants stated that developing and teaching a CURE is regarded positively in the promotion and/or tenure process at their institutions. Their institutions or departments consider the following in the promotion and/or tenure process: innovations in pedagogy, good teaching evaluations, maximizing scholarship efforts, having students conduct authentic research, and community engagement—all of which can be aspects of a CURE.

CUREs can and do result in publications in basic science and/or science education research (61%). The participants said that they could achieve authorship in the form of publications that stem from a CURE. These publications could be scientific research publications that result from the projects that students worked on or education research publications on the curriculum and/or assessment of the course.

Students collect data in a CURE that benefit faculty research programs (61%). The participants discussed specifically how the student-collected data from a CURE fed directly into their research programs—either as pilot data or as a contribution to a larger data set.

Feel self-fulfillment or satisfaction from teaching this way (47%). The participants reported that CUREs can be more intrinsically rewarding to teach than other types of courses, that they felt good about providing their students the experience of authentic research, or they felt pride about the CURE.

Teaching CUREs broadens faculty research interests (42%). The participants said that CUREs broadened their research interests because students were conducting research projects that explored new or ancillary research directions that they might not have otherwise explored. CUREs allowed the faculty to take their research programs in new directions on

Table 1. The participant-reported benefits to faculty from developing and teaching CUREs. (n = 38).

Theme	Percentage reported	Representative quotes	
CUREs are a way for faculty to connect teaching and research	76	“You have a synergy between your teaching and your research, which a traditional laboratory course doesn't.”	“I think one of the advantages in a liberal arts college is that your teaching and research are more integrated. They're not such separate activities. While you're teaching, you're getting some benefit for your research, and your research is definitely benefiting your teaching.”
Faculty enjoy teaching CUREs	74	“It's refreshing [for me]. It's new. It's novel. It's engaging.”	“It's more fun... I find it very boring if I do the same thing all the time, so I like the variety that that brings to the class.”
CUREs can contribute positively to promotion and/or tenure	68	“I think it placed me well for tenure and promotion; it prioritizes the teacher–scholar model.”	“I got tenure without a problem. I got promoted early. All of these things happened because of stuff like the research that was going on in the CURE.”
CUREs can result in publications (basic scientific and/or science education research)	61	“We can use the actual data that the students have collected during class for publications.”	“It's the best way to get research results that are for publication when you don't have time to just spend on research.”
Students collect data in a CURE that benefit faculty research programs	61	“I was trying to figure out a way to get the students to collect data for me.”	“Basically, it's going to benefit the research center, because [students are] going to get valuable data that would have been difficult to get otherwise.”
Faculty feel self-fulfillment/ satisfaction from teaching this way	47	“I just feel good about doing it. I love sharing the wealth.”	“It's way more rewarding, I think, to push students further than they thought they could be pushed and to help wake them up to science, what science is. That is incredibly rewarding to me.”
Teaching CUREs broadens faculty research interests	42	“I am investigating things that I've not investigated before. I'm researching things that I have not thought of before.”	“I wasn't doing this type of research originally but [thought] maybe it's time for me to shift to [doing] something where I can incorporate more students.”
CUREs can help in getting grant money, (e.g., “broader impacts”)	37	“It's been a springboard to get some funding.”	“It helps me get research dollars.”
CUREs are a way to recruit/train students to join faculty research labs	34	It's been a way to recruit the more talented students or the students that are really into it into my research lab.”	“Even if in the class they're not getting great data, they've gone through the process once. They can come into my research lab then; they've been trained and they can get usable data.”
CUREs connect service to teaching and/or research	24	“My teaching, my research, and service are all done at the same time.”	“It matters to us to have connections to the city. It matters in terms of our service as well—to have my teaching be folded into my service.”
CUREs help improve faculty relationships with students	21	“It's an intense class, right, so we're all bonded to each other.”	“I get to know the students a little bit more than in a typical cookbook kind of lab. We get to sit down and talk like equals about their data.”

Note: 100% of the participants made statements that fell into more than one category.

the basis of research done in the CURE, and the faculty read additional or different primary literature than they would otherwise have read in order to teach the CURE.

CUREs can help in obtaining grant money, often as a component of “broader impacts” (37%). The participants stated that CUREs could be a way to obtain grant money, either as stand-alone STEM education grants or as part of the “broader impacts” section of a basic science proposal.

CUREs are a way to recruit and train students to join faculty research labs (34%). The participants talked about recruiting students from their CUREs to join their research labs. The students in a CURE often became interested in the faculty's research and wanted to continue working on the project. Some participants developed CUREs specifically as a mechanism to train and recruit students for their research labs.

CUREs are a way to connect teaching and/or research to service (24%). The participants whose institutions expected faculty engagement with the community developed CUREs as part of their community-based service expectations. These CUREs were frequently focused on research projects that would affect and/or take place in the local community.

CUREs help improve faculty relationships with students (21%). The participants talked about getting to know their students as individuals better through the interactions in a CURE; through the repeated interactions with their students, the faculty had the opportunity to build strong rapport with those students.

Faculty perceptions of the challenges to developing and teaching CUREs

The participants also discussed the challenges to developing and teaching CUREs, from which we identified seven

Table 2. The participant-reported challenges of developing and teaching CUREs (n = 38).

Theme	Percentage reported	Representative quotes
Logistics	53	“We have vans that we can use, but I would say getting out to field sites is very tricky, both logistically and liability-wise.” “Other problems are just technical. The computer lab isn't big enough, and we don't have the software in there that I would like. It's always like, 'oh, another thing has disappeared that we used'.”
Time/work investment	34	“It takes a lot more one-on-one time with the students.” “My teaching load is really heavy, and trying to do something like this on top of a heavy teaching load is really difficult.”
Financial constraints	32	“It's just a typical lab fee, so we have peanuts to work with.” “It can be expensive, so it's more expensive for me to buy PCR kits and to do microsatellite analysis on threatened plants than it would be to, I don't know, look at plant parts under the microscope, like we used to do.”
Expanded role of instructor	29	“I have to really support them [students] and remind them that it's okay if the data don't support the hypothesis, there are setbacks and it's all good, and that's not what I'm grading them on. So there's a little bit of a morale boosting, and that's hard to sustain [for] me emotionally.” “I had to figure out how to make the students think about controls and how to get them to think about working collaboratively such that they were providing controls for each other, because money is another issue. I had to figure out how to minimize that cost and then where to get money for it.”
Research needs to be amenable to a CURE	29	“I think the challenge, though, of a research course other than the pedagogy, as my experience foretold, is troubleshooting and coming up with methods that are amenable to a course.” “You have to have projects that [CUREs] work with. That's not going to be true for everybody, every research project, so you have to think a little bit more about those research projects and do them.”
Uncertainty of research	29	“It's risky. You have to be able to willing to take on a lot of risk, I would say. You don't know that it's going to work in the end. You don't know whether or not the data that the students generate will be useful at all.” “I guess I would say dealing with the unexpected. It's not all rehearsed, so you never quite know what's going to happen and being able to adjust the assessments you might use if an experiment absolutely fails. By that, I mean not that you get results that you're not expecting but that for some reason it just does not work.”
Student resistance	21	“Students really prefer the cookbook because there's a lot of uncertainty and ambiguity in our project. If things don't work, students freak out about that.” “They work in groups. That's the other thing, I guess, that is a challenge. At first, some of them don't want to work in groups and are very weary of it or have been burned too many times by groups.”

Note: 89% of the participants made statements that fell into more than one category.

distinct themes. Altogether, 89% of the participants made statements that fell into more than one theme; representative quotes of each theme can be found in table 2 ($n = 38$). The mean number of challenge themes stated by each participant was $2.7 (\pm 0.17 \text{ SEM})$.

Logistics of teaching a CURE (53%). The participants highlighted that a major challenge was the logistics of knowing what supplies to order and when and arranging for students to have extra time in the lab to finish their experiments. This also included logistical issues related to field-based CUREs, such as transportation to and from field sites.

Time and work investment (34%). The participants discussed the heightened amount of time and effort that went into planning and implementing the CUREs, including being present in the lab room and having more face time with students than they would have had in a non-CURE course.

Financial constraints (32%). The participants mentioned that the cost of the CURE, particularly the lab supplies, could be more than that of a non-CURE lab course. Specifically, they reported that small course budgets and the lack of institutional or departmental monetary resources could be a challenge.

Expanded role of instructor (29%). The participants discussed playing a greater variety of roles as the instructor of a CURE than they would in a traditional lab or lecture class. They highlighted needing to be a mentor, guide, or counselor to students in the course—similar to the role of a mentor in a research lab. They discussed how it was a challenge to keep track of and consult on numerous simultaneous projects, some of which pushed the bounds of their expertise.

Research needs to be amenable to a CURE (29%). The participants talked about needing to find a scientific research project that could be conducted in a lab course given the constraints of time, funding, and student interest and ability level. They indicated that it could be difficult to transfer what a faculty member does in their research program to a lab course.

The uncertainty of scientific research (29%). The participants indicated that because the students in CUREs are working on real research problems with unknown answers, the experiments may not always go as planned, and the data collected may not be usable. Furthermore, it is difficult to plan exactly what is going to happen each day, and the research project may venture into unknown territory for both the student and the faculty.

Table 3. The attributes of someone who would be good at teaching and developing a CURE (n = 31).

Theme	Percentage reported	Representative quotes	
Ability to deal with uncertainty	52	“To a certain extent, being willing to dive in and roll with the punches.”	“I would say be willing to take risks and allow things to fail. Know that students are going to learn whether it's successful or not.”
Background in research	26	“They have to have the knowledge and the research skills.”	“Anyone who has a PhD has the experience I think to do it.”
Willingness to invest time/effort	23	“They have to be willing to work really hard—harder than is expected.”	“You have to be willing to put in a lot of extra work, usually at the beginning.”

Note: 16% of the participants made statements that fell into more than one category.

Student resistance (21%). The participants stated that student buy-in could be challenging. CUREs often require collaboration, and students may not like working in groups. It is also a different type of learning from what students might be used to, so some students may not want to be challenged to think on their own without being told what to do or given answers.

Institutional support was not a salient barrier to our participants undertaking a CURE

We found that 71% of the participants talked about having institutional or structural support in the form of a supportive department chair, department, and/or administration who helped, supported, or simply allowed them to develop and teach CUREs without a hindrance.

Faculty perceptions of the necessary attributes to develop and teach a CURE

To gain insight from faculty who were experienced in CUREs, we asked our interview participants, *If you chose a faculty member to develop and teach a CURE, what attributes would you be looking for?* We identified three thematic categories of attributes recommended by our participants; 16% made statements that fell into more than one category (table 3), and the mean number of attribute themes stated by each participant was 1.2 (± 0.16 SEM).

The ability to deal with uncertainty (52%). The participants talked about how someone teaching a CURE should be able to deal with uncertainty in the CURE. Research projects involve inherent uncertainty, so one needs to be flexible and comfortable with not knowing what the results will be or what exactly will happen during each class period. Furthermore, the students might be doing different experiments at different times, so one needs to be able to handle a certain level of chaos in the classroom.

A background in scientific research (26%). The participants stated that someone needs experience and/or expertise in conducting scientific research and that to guide a course-based research project, one needs general proficiency in that particular area of research.

A willingness to invest the necessary time and effort (23%). The participants thought that someone should have the willingness

and motivation to follow through with a CURE and the willingness to put forth sustained time and effort that developing and teaching a CURE may require.

Discussion

Faculty who develop and teach their own CUREs reported a number of benefits for themselves resulting from CUREs, many of which arose with a strong consensus among participants. Challenges to developing and teaching CUREs were identified with slightly less agreement among participants, and three themes of desirable attributes of someone who may be well-suited to develop and teach a CURE were identified in our faculty interviews.

Faculty can connect teaching and research

The most frequently reported faculty benefit was integrating teaching and research through CUREs (76%). In Boyer's (1990) influential report, *Scholarship Reconsidered: Priorities of the Professoriate*, he urged faculty to integrate research, teaching, and service as scholarship. Subsequent studies and reports have lauded Boyer's (1990) ideas and outlined how to diversify and expand the profile of the professoriate through rewards for excellence in endeavors such as teaching and community engagement (Glassick 2000, Antonio 2002, Arreola et al. 2003, Austin and McDaniels 2006). Our data suggest that CUREs offer a mechanism by which faculty can merge these often-disparate aspects of their academic scholarship. CUREs can help blend away forced disconnects between teaching and research and, in some cases, also merge scholarship with service (table 1). More than half of the participants talked of the ability to gain tangible academic currency through CURE publications—an ultimate example of merging research scholarship with teaching. The majority of the participants also identified that CUREs can be viewed positively in cases of promotion and tenure, further highlighting the significant potential of what faculty may gain through CUREs.

The intrinsic benefits from CUREs

In addition to scholarship-related benefits, 74% of the participants spoke of enjoying their time in the CURE classroom, and almost 50% reported feeling self-fulfillment from developing and teaching CUREs (table 1). Although not directly leading to tangible rewards, these themes of

interest and personal enjoyment appear important for CURE instructor satisfaction and therefore could be fundamental for CURE sustainability. Researchers have identified that both extrinsic and intrinsic values and gains are vital to one's overall motivation to take on tasks, job satisfaction, and longevity in academia (Olsen 1993, Feldman and Paulsen 1999, Eccles and Wigfield 2002, Lechuga and Lechuga 2012). The relative importance of intrinsic gains for faculty as a result of CUREs is an intriguing avenue for future study.

The challenges in developing and teaching CUREs

Faculty perceptions of barriers to instructors integrating research into courses have been examined both generally (Spell et al. 2014) and for specific CURE networks (Lopatto et al. 2014, Shaffer et al. 2014). However, to date, no one has examined the challenges that faculty who develop and teach their own CUREs face. Here, we found that the faculty who develop and teach independent CUREs, unsupported by a network, discussed overlapping barriers to those previously reported, including logistical hurdles and increased time investment. There are also novel challenges that emerged from our study, including that the research project itself needs to be amenable to scaling-up to a classroom setting and that faculty have to juggle expanded roles as the instructors of CUREs, perhaps more akin to being an advisor or mentor than a lab instructor (table 2). Furthermore, the *inherent uncertainty of research* theme indicates that some CURE projects may fail, and this can have a direct effect on whether CURE data is publishable or useable by the faculty. This theme may have uniquely emerged from the faculty developing and teaching their own CUREs because there may be more at stake for these faculty if student-collected data cannot be used beyond the course in the faculty member's research program.

The participants faced challenges to developing and teaching CUREs from both inside and outside of the classroom, but our participants have largely persisted in teaching CUREs. This indicates that they have found ways to overcome, or at least tolerate, the challenges. Importantly, the participants rarely discussed significant structural impediments to CUREs. In fact, 71% of the participants explicitly mentioned that their departments, department chairs, and/or institutions were generally supportive of their CUREs. We suggest that if adequate structural support for CUREs is provided from departments and/or institutions, the challenges to developing and implementing CUREs may be surmountable.

Faculty may already have what it takes to develop and teach CUREs

The participants identified attributes that they felt a colleague should have in order to be successful at developing and teaching a CURE. Overall, 52% discussed that being flexible and able to handle uncertainty when teaching a CURE is crucial (table 3), which is related to some of the challenges that the faculty reported facing in the CURE

classroom (table 2). A number of participants reported that someone would need to have the experience or expertise of a researcher to develop and teach a CURE, but interestingly, the theme that faculty would need to have teaching experience and/or teaching expertise to develop and teach a CURE did not emerge from these interviews. The focus on research expertise in our data could be an artifact of our particular study group, although individuals with both research-intensive and teaching-intensive positions are represented in our sample (appendix S2). We posit that the faculty did not discuss the need for teaching expertise because they perceived CURE instruction to be an extension of mentoring in the research lab, where research is purposeful and teaching occurs more organically. Therefore, there may be the perception that the CURE instructor needs research expertise but not necessarily teaching expertise. Another possibility is that our participants assumed teaching expertise to be an implicit quality of someone who is in the position to develop and teach a CURE.

Brownell and Tanner (2012) postulated that when a faculty member's professional identity is that of a research identity, it may be a significant obstacle to pedagogical change. However, CUREs could be an exception to this. Our data imply that research training—and potentially a research identity—may be an important attribute of CURE instructors. CUREs could offer a means by which someone with a strong research identity can still teach in ways aligned with calls for undergraduate reform, presenting a mechanism to engage research-intensive faculty in the national movement for life sciences laboratory reform (NRC 2003, Brewer and Smith 2011).

Nuances, limitations, and next steps

The themes of the benefits, challenges, and perceived attributes of successful CURE developers and instructors emerging from this data set provide a foundation for future studies to further explore faculty perspectives on CUREs. We acknowledge that our study participants likely represent a best-case scenario in terms of enthusiasm and support for CUREs, as well as in tangible benefits such as publications. However, this exploratory study indicates that faculty from a variety of positions and career stages, disciplines, and institutions can gain similar benefits from CUREs. Future studies sampling a larger number of individuals who teach different types of CUREs may reveal trends in perceptions of CUREs among individuals by factors of rank, gender, or institution type.

Benefit themes such as *CUREs connect teaching and research* may have divergent meanings to faculty members with different job expectations in varying types of institutions. Faculty at research-intensive institutions may already be meeting their research needs (e.g., publications) in their independent labs, so they may be using CUREs as a way to enhance their teaching. Alternatively, faculty at liberal arts colleges may not be meeting their research needs in their independent labs because of high teaching obligations, so they may be using CUREs as a way to synergistically teach

and accomplish research. These could be untangled in future studies as we continue efforts to understand CUREs from a holistic perspective.

Conclusions

National calls for the transformation of undergraduate biology education stress that more students should have the opportunities to engage in research, and CUREs make these recommendations a reality (Weaver et al. 2008, Brewer and Smith 2011, Kloser et al. 2013, Auchincloss et al. 2014, Bangera and Brownell 2014, Jordan et al. 2014, Shaffer et al. 2014). As the field grows, we must continue to rigorously develop explicit ways to evaluate the outcomes of CUREs for both students and faculty (Brownell and Kloser 2015). This study is the first to focus on the perspectives of faculty developing and teaching independent CUREs and thereby lays important groundwork for more comprehensive studies related to the faculty experience in CUREs. As our data suggest, it is not only the students who can benefit from CUREs but faculty as well. Therefore, we recommend promoting faculty benefits as a way to incentivize the widespread implementation of research in the undergraduate classroom.

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Supplemental material

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