Physics Instructor Views on Course-based Undergraduate Research Experiences (CUREs)

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Undergraduate research experiences are beneficial students. However, the over-subscription of traditional research opportunities combined with other barriers prevent many students from participating. A promising alternative is a course-based undergraduate research experience, or CURE. CUREs are shown to have similar outcomes to traditional research experiences, while reducing the barriers to participation and providing an authentic research experience to an entire cohort of students. Within STEM disciplines, physics has been identified as underrepresented in CURE implementation. The broad scope of our work is to identify the challenges and opportunities for creating and sustaining physics CUREs. As a first step, we conducted a series of interviews with physics instructors from multiple institutions to collect faculty views on implementing and sustaining CUREs. We present the results from the analysis of these interviews and discuss barriers, learning goal priorities, and potential CURE benefits identified by instructors.

2024 PERC Proceedings edited by Ryan, Pawl, and Zwolak; Peer-reviewed, doi.org/10.1119/perc.2024.pr.Merritt

I. INTRODUCTION & BACKGROUND

Participating in research has been shown to be beneficial to undergraduate students across many dimensions[1–5]. Some of these benefits include persistence in a degree program [6], improved performance in STEM courses [5], the ability to think and work 'like a scientist' [7, 8], development of transferable research skills[9], and opportunities for students to facilitate relationships with senior scientists and their peers [4]. Students who participate in undergraduate research have also been shown to have increased interest in, and preparedness for, entering the STEM workforce[10]. These outcomes can be particularly beneficial to students from marginalized groups [3, 6, 11–14].

However, there are many barriers to student participation in traditional undergraduate research experiences (e.g., a student working within a research group mentored by a faculty member, postdoc, or graduate student in apprenticeship style training). The demand for research experiences is greater than the supply; many departments do not have the resources to provide traditional research opportunities to all or even most students [4]. Because of the lack of supply, strict selection criteria (e.g., minimum course grades [13]), which may or may not be an indicator of research potential, are commonly used in choosing undergraduate researchers. This can result in capable students being excluded from research opportunities. Additional barriers may include students not being aware of the opportunities available or how to pursue them [15] and financial or other personal barriers (e.g., family caring) that make a traditional research experience not feasible [14, 16].

A potential alternative to traditional undergraduate research are Course-based Undergraduate Research Experiences, or CUREs. CUREs provide entire classes of students the opportunity to explore a research question that is of interest to the scientific community or community beyond the classroom [17], while reducing the participation barriers noted above. As defined by the CURE Network (CUREnet) [18], CUREs consist of five key components: (1) use of scientific practices, (2) discovery, (3) broadly relevant or important work, (4) collaboration, and (5) iteration. An in-depth description of each of these components can be found in Auchincloss *et al.* [4]. Although many laboratory courses have some of these components, what distinguishes a CURE is the integration of all five components.

It has been shown that students who participate in CUREs experience similar benefits as students who participate in traditional undergraduate research experiences, including persistence in STEM, career clarification, and identity as a scientist [5, 17, 19–21]. However, there are challenges to developing, implementing, and sustaining CUREs. These challenges can range from choosing an appropriate research question for students to explore to preparing graduate teaching assistants to support students in this type of course, to being able to adapt the course when the research question has been answered [22]. Despite these challenges, over 240 STEM CUREs have been reported in the literature in the last 20 years [23], with the majority of CURE growth happening since 2014. In their overview, Buchanan et al. report that ∼87% of CUREs occur in biology and chemistry. So, where does this leave physics CUREs?

Physics was identified as a field where CUREs are lacking in the literature and are underrepresented in the national curriculum [19, 23]. However, there are a few examples of successful physics CUREs. Recently, the Colorado PHysics Laboratory Academic Research Effort (C-PhLARE) CURE, the first remote, large-enrollment, introductory physics CURE, took place at the University of Colorado Boulder (CUB). Designed in response to the COVID-19 pandemic, the C-PhLARE CURE ran for three semesters and involved more than 1400 undergraduate students. The focus of the CURE was to explore the heating mechanism of the solar corona, with students working in small groups to analyze their own solar flares. The results of this CURE were published in *The Astrophysical Journal* with around 1000 student co-authors [24]. A full overview of the course can be found in Ref. [25]. When examining course artifacts, researchers observed similar positive impacts on students as seen in other CUREs. Students reported gains in their research and coding skills, increased motivation and interest in experimental physics research, and that they experienced productive and enjoyable teamwork opportunities in the course [26, 27]. On CUREnet, there are currently only two physics CUREs listed. The first is examining catastrophic cancellation in a traditional elastic collision lab experiment [28, 29]. The second is a geophysics CURE comparing geophysical methods for detecting cave features and determining the position and elevation of minor cave passages on the Bracken Preserve [30]. There have also been instances of 'CURE-like' Authentic Learning Experiences (ALEs) in physics, such as the combined upper- and lower-division American River ALE at the California State University, Sacramento [31]. The students in an upper-division electronics course built instruments capable of measuring depth, turbidity, and temperature of the river. The students in the lower-division physics course then characterized, tested, and provided feedback on the instruments.

The combination of the positive impacts seen in the C-PhLARE CURE and similar courses with the lack of physics CUREs raised the question 'what can be done to support more physics CUREs?', which has motivated our work. There are two main goals for this project. The first is to identify the challenges and opportunities to implementing and sustaining physics CUREs. The second is to develop a framework of effective practices to support the creation of more CUREs in physics. The framework of effective practices will include topics such as questions to ask a potential science mentor to find a good project fit, assessment methods to measure the impact of the course, and materials for training graduate teaching assistants (TAs) and undergraduate learning assistants (LAs). These goals will be accomplished through two related efforts. First, we are developing and implementing a new CURE at CUB. Beginning Fall 2024, students in a sophomore-level physics lab course will be investigating the external quantum efficiency of solar cells. The course is required for physics, astrophysics, and engineering physics majors and serves ∼200-250 students per academic year. Through this process, we will learn about some of the challenges and how to overcome them in this particular setting by running the new course and gathering input from all parties involved in this CURE - instructors, TAs and LAs, and undergraduate students who will take the class. The second effort is to make sure that the framework developed is applicable beyond CUB. Therefore, we began this project by interviewing instructors from many types of institutions with a variety of student demographics in order to better understand the broader opportunities and concerns for implementing and sustaining physics CUREs.

Here, we will (1) present an overview of the instructor interview process and how the data were analyzed, (2) discuss several takeaways from the instructor interviews, including learning goal priorities and instructor identified barriers and benefits to CURE development and implementation, and (3) share next steps in the framework development process.

II. METHODOLOGY

A. Faculty Interviews

We recruited faculty members and lab instructors to participate in interviews via email. The initial contact list of ∼120 instructors was compiled from connections to professional organizations (e.g., Advanced Laboratory Physics Association), instructors who were in the professional networks of the authors, and the faculty at our home institution. While compiling the contact list, we were sure to include a variety of institutions, including two-year colleges and minority serving institutions (MSIs), and instructors from a variety of positions from lab coordinators to department chairs. Our final sample consists of 33 instructors from 19 different institutions. Of the 19 institutions, there were six R1s, two R2s, five masters/professional colleges and universities, five four-year colleges, and one two-year college. Three of the institutions are minority serving intuitions. Those interviewed self-identified their gender and race/ethnicity. Of the 33 interviewed, 24 identified as men and nine identified as women. Twenty-nine identified as White/Caucasian, two identified as Asian, and two identified as African American. Thirty of those interviewed were teaching or research faculty, five of which currently are or have been department chairs. The remaining three were lab coordinators. The instructors came from a variety of physics backgrounds - experimentalists and theorists from a large range of subdisciplines of physics.

The interviews lasted about one hour and were conducted either over Zoom or in person. The interview protocol consisted of three main components. The first was to obtain background information about the interviewee (e.g., role in department, research background), their current first and second year lab curriculum, and currently implemented and aspirational learning goals for those courses. The second component probed instructors thoughts about CUREs - how familiar they were with CUREs, input on the CURE components, what types of CURE projects they thought would be appropriate for a lab course (e.g., computational versus more traditional hands-on) and what types of equipment students should be interacting with. In the final component, faculty shared their thoughts on what might be potential benefits and challenges for each stakeholder group (i.e.,instructors, TAs/LAs, and undergraduate students) participating in a CURE, as well as the resources that would be necessary to develop, implement, and/or sustain a CURE.

B. Data Analysis

The audio recording from each interview was transcribed through an automated transcription service and then corrected manually. We analyzed the interview transcripts through a qualitative coding process [32] beginning with a set of *a priori* codes, which were determined by the interview protocol. These codes included instructor-perceived barriers to CUREs, learning goals and outcomes, the CURE components, and instructor-identified resources for CUREs. Subsequent passes through the data resulted in additional emergent codes. For example, the barriers to CUREs were split into three types of barriers: development, implementation, and sustainability. A set of sub-codes emerged for how instructors believed the CURE components are implemented, if at all, in their current curriculum. Twenty sub-codes emerged for specific learning goals and outcomes, including topics such as data visualization, computation, and error analysis.

After the full codebook had been created, we performed inter-rater reliability (IRR). Author RLM and a researcher, who had not participated in the protocol development or interview process, separately coded three interviews, which were chosen to be from instructors with different roles in their departments. After the coding, the researchers discussed any discrepancies and resolved them, which resulted in the final codebook. With the final codes, 10 excerpts were compared from the barriers, resources, and benefits codes (30 excerpts in total). Cohen's kappa [33] was calculated for each set of excerpts, resulting in κ values of 0.92, 0.87, and 0.93 for the barriers, resources, and benefits codes. Cohen's kappa values greater than 0.8 are considered to be 'almost perfect agreement' [33], therefore our IRR results are acceptable. An abbreviated version of the final codebook listing only the main codes can be seen in Table I.

III. RESULTS & DISCUSSION

With nearly 30 hours of interview data, we have a wealth of instructor input to inform the framework and our own course design. Here, we will share results on the following topics: instructor priorities for learning goals and course outcomes, aspects of the CURE components instructors would like to see emphasized, and main resources instructors would require if they were designing and implementing a CURE.

Learning Goals and Outcomes During the interviews, instructors were asked, in the context of their first and second year lab courses, "*What are the main outcomes you would want students to achieve? These could be things that are currently happening or that you would like to happen*." This

TABLE I. Abbreviated Codebook for Instructor Interviews.

Main code	Main code description
Barriers	Perceived difficulties that impact the development, implementation, or sustainability of a CURE
Benefits	Benefits identified for instructors, TA/LAs, and undergraduate students participating in a CURE
CURE Components	Components implemented in current curriculum; Components identified as instructor priorities
Learning Goals/Outcomes	Current and aspirational learning goals and outcomes for first and second year lab courses
Acceptable of types of physics/projects	Appropriateness of physics subfields and projects types (e.g., data analysis only) as CURE projects
Resources	Resources (e.g., Time, Personnel, Financial) that would assist with development of CUREs
Sustainability preference	Instructor preference for sustaining CUREs (e.g., perpetual project versus fully renewing project)
Tool/Instruments	Tools and instruments instructors identified as important for students to engage with in a lab course
Demographics information	Gender, race/ethnicity demographics; Role of instructor in department; Instructor physics background; Information about current lab curriculum; Level of familiarity with CUREs
Miscellaneous	Misc. instructor opinions (e.g., what level should CUREs be introduced to the curriculum)

question was asked prior to the CURE specific discussion. The five learning goal topics most frequently identified by instructors were error analysis/propagation (N = 26), data analysis (24), experimental design (21), programming (17), and writing (15). Considering these in the context of the CURE components, four of the five most prevalent goals are related to the *Use of Scientific Practices* component, with experimental design being the only one that is related to multiple CURE components. Experimental design is also the learning goal that was more aspirational than currently being implemented in the first and second year curriculum.

CURE Priorities The priority on including scientific practices in courses was further emphasized when instructors were asked about the CURE components in the second part of the interview. Instructors were asked *I think we can agree that all of these components are important, but if you had to rank them, what would be your top two and why?*. Unsurprisingly, $\sim$75% of instructors selected the *Use of Scientific Practices* component as a priority. After scientific practices, the *Collaboration* and *Iteration* components were selected by $\sim$50% of instructors as priorities. Although all five component must be present for a course to be a true CURE, understanding instructor priorities will be useful in developing the framework.

Continuing to probe instructor opinions about the CURE components, we also asked if they thought there were any components missing or aspects of the components they would like to see emphasized during a CURE. All of the components the instructors identified as important were contained within the existing five CURE components, but there were two aspects that instructors would like to see emphasized. First, 11 instructors wanted to see an emphasis on communication, which is contained in both the *Use of Scientific Practices* and *Collaboration* components. In terms of scientific practices, the emphasis was on the more formal communication of results, with one instructor saying:

> Communication...[is] something that...students in general don't really associate with science. They think, 'Oh, I'm not doing liberal arts, I'm doing science, it's all math.' And no, you actually have to write and you actually have to talk and you have to be really good at both of them if you're going to be successful in the field.

The other emphasis, which is a component of collaboration, was on students learning how to communicate with their peers, especially in situations that may involve disagreement or conflict. Based on their experiences, one instructor said:

> I wish there was some way people could learn that when you have a contentious scientific discussion, there are ways to do it, which are polite, and which encourage advancement.

Second, 14 instructors also wanted to see the frustration/failure aspect of the *Iteration* component emphasized. One instructor said:

> I am aware that frustration tolerance is...lacking and can be a huge impediment.

From the instructors that wanted to see an emphasis on frustration and failure, there was an common thread of students not having the opportunity to acclimate to the discomfort with the 'messiness' of experimental science, in that in authentic research you do not know the answer and your methods may not work correctly the first time [34]. In more traditional lab course settings, when students encounter difficulty with an experiment or analysis, they able to be directed by a TA or instructor to the known answer with minimal need to iterate on their own. The lack of supported opportunity to iterate on an unknown answer can cause students to negatively internalize failure when it occurs with one instructor saying:

> You can't go through life and not make a mistake on something...there needs to be this supportive thing, that when you make a mistake, on an experiment or an analysis, it's just part of experimental physics, and it's not a value statement.

In a CURE, instructors and TAs will be able to help troubleshoot and problem solve, but due to the nature of the course, they may not know the 'correct answer' either. This will provide students with the opportunity to work through the ‘messiness’ with the instructor or TA, allowing them to gain confidence with that process.

Barriers and Benefits Moving from CURE components to CURE design and implementation, we asked instructors what resources they would need to successfully design and implement a CURE. A resource mentioned by 29 of the instructors was time, with an instructor saying:

> Like there’s a fixed amount of time, your classes aren’t given more time, you’re not given more time. But this task takes an enormous amount of time and enormous amount of caretaking.

Doing any kind of curriculum development is time intensive and instructors noted that additional resources, such as course releases and summer salary would be required to be able to design a CURE.

The second resource instructors identified was personnel(N=14), specifically TAs and LAs. One the two instructors who taught a CURE expressed the need to prepare to manage TAs who would be assisting with the CURE, saying:

> The part...that I couldn’t imagine just brute forcing my way through...was managing the TAs.

Due to the nature of the course, being a TA for a CURE is different than being a TA for a traditional lab. Knowing this, we asked the instructors if they would find suggestions for preparing and managing TAs for a CURE helpful. All instructors said they would find TA documentation useful and so we will be including it in the final framework. In general, instructors expressed interest any guidance that could be provided by the framework with one instructor saying:

> Having example...homework, [TA] roles or whatever, however it gets structured, just having I guess, the exhaustive documentation...that can be followed would be very helpful.

Finally, there was minimal concern from instructors that they would not receive support at the department or college level. The more authentic nature of CUREs combined with many institutions’ push towards more career readiness made instructors think that they would not get much objection and may, in fact, get departmental and/or institutional support to implement a CURE. There were also a small number of instructors that said that funds or other physical resources, like equipment, could be a barrier to CURE development.

While acknowledging potential hurdles for CURE implementation is important, it is equally important to acknowledge instructor enthusiasm for, and perceived benefits of, CUREs. Instructors talked about CUREs providing more of their students the opportunity to participate in research. They also expressed that the authentic nature of CUREs will help prepare students for their next career step, with one instructor saying:

> If you want to know what it’s like to be professional, there’s no other way to do it than to be a professional.

Instructors also saw benefits for themselves, ranging from building meaningful relationships with more students to the *Discovery* component of CUREs adding excitement to the courses they teach.

IV. SUMMARY & FUTURE WORK

These interviews provided useful insight to instructor thoughts about CUREs. We found the majority of instructors identified time to create a new course and appropriate training of graduate teaching assistants for this new environment as the largest barriers to developing and implementing CUREs. Despite the potential barriers, the instructors were interested in, and open to, the implementation of CUREs. Instructors indicated they would like a CURE to emphasise communication and the opportunity for students to gain more comfort with the frustration and failure aspects of the scientific process. These data are currently being used to inform the first iteration of a physics-specific CURE framework. This framework is being used to guide the development of a new CURE that will begin in Fall 2024 and will be updated as need as through the next couple of semesters. Once the framework is finalized, we will again engage with instructors to make sure the framework is applicable outside of CUB.

In our next steps, we will be getting input from the other parties involved in the CURE at CUB - the teaching and learning assistants and the undergraduate students. We are currently in the process of interviewing TAs from the pre-transformation course. We want to probe their views on their current workload and enjoyment of TAing, their perception of their role in the course, what career skills they are gaining from TAing, and how TAing impacts their science identity. The interviews will be repeated with the TAs from the transformed course in upcoming semesters. Additionally, the TAs working in the CURE will submit weekly reflections updating the research team and course instructor of what things are working in the CURE and what things are not as successful.

Finally, to gain insights from students taking the course, we are analyzing writing assignments from the current version of the course. The purpose of these assignments is to look at connection between coursework and authentic research (scientific practices, failure, relevant discovery, agency, collaboration, successful science). These assignments will also be used in the CURE and we will conduct a comparison analysis. We will also be interviewing undergraduate students from both the current course and the CURE to further probe the impact course modality has on students. The combination of instructor, TA/LA, and student perspectives will help inform a set of well-informed practices that will help support the creation of more physics CUREs.

ACKNOWLEDGMENTS

This work is supported by the NSF Mathematical and Physical Sciences Ascending Postdoctoral Research Fellowship program (PHY 2316504) and PHY 2317149. We would like to thank the faculty who participated in the interviews for their time and input and Micah Kretchmer for his feedback on this work.

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