

Fear of the CURE: A Beginner's Guide to Overcoming Barriers in Creating a Course-Based Undergraduate Research Experience†

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Over the past decade, growing evidence has shown that there are many benefits to undergraduate students engaging in scientific research, including increased persistence in pursuing STEM careers and successful outcomes in graduate study. With these benefits in mind, there has been a significant push toward providing research opportunities for students in STEM majors. To address this need, an increasing number of undergraduate courses have been developed to provide students with research experiences in a class setting, also known as course-based undergraduate research experiences, or CUREs. Despite the growing success of these courses, a number of barriers remain that deter faculty from developing and implementing CUREs. Here, we will review the perceived challenges of developing a CURE and provide practical strategies to overcome these challenges.

INTRODUCTION

Exposing students to research experiences is key to engaging and recruiting the next generation of scientists (1–3). To emphasize the process of scientific investigation and discovery in a classroom setting, course-based undergraduate research experiences, or CUREs, were developed (4). Evaluation of CURE courses has identified five core components that distinguish them from traditional laboratory courses: iterative experimentation, collaboration, discovery, broad relevance of the research question to the community, and generation of data (5).

CUREs offer numerous benefits for students, including increasing access to research opportunities for all students and, notably, narrowing the achievement gap between the highest performing students and their peers (6–9). CUREs can be particularly impactful for students traditionally underrepresented in STEM, through increases in psychosocial outcomes, knowledge acquisition, and persistence in STEM fields (10). CUREs also present marked benefits for instructors, departments, and institutions, including student retention and the creation and collection of research data at primarily undergraduate institutions (11). While there is ample evidence demonstrating the benefits of CURE-based

approaches (12–14), there are fewer resources that address specific strategies for CURE implementation, overcoming potential barriers, and implementing one's own unique CURE. The goal of this review is to provide a practical guide to developing a CURE-based approach and help readers overcome any fears that may be holding them back.

PERCEIVED BARRIERS AND SOLUTIONS TO STARTING A CURE: I AM A BELIEVER, BUT NOW WHAT?

Fear of the topic of the CURE

Identifying a research topic is a common concern for faculty designing and developing CUREs. In particular, instructors are wary of adapting research projects to a classroom laboratory defined by set hours, location, and equipment (12). Fortunately, as CUREs have become more common (both in implementation and as the subject of educational research), so have resources for identifying research ideas to implement in classroom settings (15). There are now numerous papers outlining CURE courses being taught on a wide variety of topics (16–18) and websites containing project ideas for CURE courses (see Appendix 1). Additionally, several professional scientific societies, including the American Society for Microbiology and the Genetics Society of America, have embraced CUREs and offer workshops and resources to assist in course development (19). Networking within these workshops can be a valuable resource for mentorship as you embark on CURE development.

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Fear of the scale and scope of CUREs

In planning a CURE, instructors must seriously consider how available space and resources will shape their course design. CUREs can range from a module inserted into an established laboratory course to stand-alone research projects lasting the entire semester and thus can be implemented in a variety of course types. Many large institutions have implemented CUREs in large introductory lab courses [e.g., First year Innovation and Research Experience (FIRE) at the University of Maryland, the Freshman Research Initiative (FRI) at UT at Austin, and the Place-Based Learning Communities (PBLC) at Humboldt State University] (see Appendix 1). Determining the scale and scope of a CURE may seem daunting at first, but the key is to start small and allow your course to evolve over time. Even those implementing CUREs in large introductory lab courses began with a small pilot cohort of students (20).

Here, we describe three approaches to implementing a CURE that could be considered as follows: 1) incorporation into the existing course structure, 2) use of a national network model, and 3) investigations that align with a faculty research area. While these represent a few common CURE approaches, there are many variations on these designs, and approaches will vary from course to course.

Approach 1: Incorporation into the existing course structure. This approach is focused on developing a short inquiry-based lab module that can be scaffolded onto an existing course structure. The advantage of this approach is that it does not require a whole-course revision, and faculty have the resources to enable implementation. Modifying an existing “cookbook” lab to generate an open-ended inquiry-based lab experiment requires relatively minimal time investment and there are many resources, such as CUREnet, that can provide protocols and ideas for getting started. For example, the Prevalence of Antibiotic Resistance in the Environment (PARE) project provides tools for an extension of a common microbiology laboratory exercise involving the enumeration of bacteria from a soil or water sample (21). Specifically, students enumerate the number of tetracycline-resistant bacteria from a soil sample and contribute their findings to a national database. The approach provides flexibility for students and instructors to choose what they will sample, without knowing the outcome, to come up with a rationale for their results, and to connect to the broader scientific community. Extensions to this module have been developed by instructors to include statistical and data analysis or molecular identification of antibiotic-resistant bacteria in the environment. While a single CURE module will be smaller in scope and depth than a full-term course, it may be ideal for trying out new methods or performing feasibility studies in order to gauge practicality for use in the undergraduate laboratory.

Approach 2: Use of a national network model. In the national network model for implementing a CURE, students become part of a larger team probing a research

question (12). With this method, the protocols and course delivery methods are already in place and the classroom automatically becomes part of a larger scientific community. Students collect data that become part of a national repository and collaborators provide assistance along the way. There are many examples of these national network projects, including SEA-PHAGES (22), the Great Sunflower project (23), and the Small World Initiative (24), that can be adapted for use in the undergraduate classroom laboratory. For bioinformatics courses, Reeves *et al.* (25) recently described a large-scale implementation of functional genomics research for introductory biology students that showed tremendous growth in several areas, including content knowledge, database use, and collaboration.

Approach 3: Investigation aligned with a faculty research area. CUREs can also align with faculty research interests. For some faculty, this strategy is appealing, because the CURE course may provide additional lab “hands.” However, unlike students in traditional undergraduate research settings, these students have not selected this research area and instructors have not selected the students (26). In this scenario, it is vital to engage students in the research problem by providing them with relevance, illustrating current knowledge in the field, and posing questions that students can address in a classroom setting. In this type of CURE, all students may address a similar research question but take different approaches. Instructors may need to provide more guidance and direction in the beginning to avoid a completely “open-ended” research experience.

While this type of CURE may take more time and investment to get started, it could also provide a pipeline for the collection of preliminary results and may spark student interest in your research laboratory. In addition, students can gain skills that allow them to advance more quickly in an apprenticeship model research experience. Students know that they are contributing to the lab’s work, may become authors on publications, and feel more like a part of the laboratory community (27).

A commonality to CURE approaches: student-centered inquiry. Although less formalized as a CURE model, student-centered inquiry can be a common element of CURE approaches. It begins by allowing students to develop research questions that can be investigated by applying tools and techniques that they have learned, or are currently learning, in your course. This CURE model gives students ownership of research design, while faculty and teaching assistants serve as guides rather than dictating what is to be studied. Students may also be encouraged to investigate a research question that holds personal relevance for them and/or their community.

Students need ample time to conduct background literature research and in-class time to design and plan their experimental approach. Planning ahead for brainstorming, peer review, and instructor feedback is key for student success in any type of CURE.

Fear of the time and effort

A central outcome to any CURE is to provide students with a laboratory research experience. However, accomplishing research or experimental goals within the scheduled class time can be a challenge. This time constraint is further intensified by working with biological systems, whose maintenance and upkeep may not be on the same time scale as the planned course schedule. While support from a graduate or undergraduate teaching assistant can certainly lessen the preparatory workload, we propose some additional considerations for addressing time management issues that arise (Table I).

One time-saving strategy requires building in time for planning and iteration. Assigning certain writing tasks, such as a proposal outline or request for materials, will ensure that students come to class prepared to work on their projects independently. In this planning phase, students also gain an understanding of the essential role that time, money, and resources play in scientific research. By outlining and modifying their experimental plan, students have a framework for then rethinking, troubleshooting, and redesigning their experiments based on their results, just as they would in a research laboratory setting. In fact, experiencing research iteration is one of the most beneficial aspects for students in a CURE (5, 14). Including these iteration steps within your CURE will promote greater efficiency and save time and effort in your implementation.

A collaborative solution that can help ease the instructor’s time burden is the dividing up of common lab chores, such as stock maintenance or other weekly “prep” tasks that can be assigned to groups on a rotating basis. Some groups have described a “walk-in” lab set up or “open lab” time when students can accomplish these tasks outside of class time. To address the time constraints faced by many students, especially at large commuter campuses, allow for extra in-class time for prep work, even if it means reducing the number of experiments that the students attempt during the semester. In this case, less can be more.

Fear of the cost of a CURE

It will be of little surprise to readers that research is expensive! Cost does matter in selecting a CURE approach. Location, resources, type of institution, and student level are all factors to be considered.

Funding for CURE courses may come from a variety of sources. At the campus level, grant opportunities may include curriculum development funds, interdepartmental collaborative grants, or fellowships geared toward teaching. CUREs may also be funded through institutional support and may align well with institutional priorities, including preparation for careers in STEM professions. For example, articles based on interviews with employers in diverse STEM fields all highlight the importance of developing students’ “soft” skills (28, 29). Since a variety of soft skills are also

TABLE I.
Timeline and checklist for developing and implementing a CURE.

Before the Course Starts	During Implementation	After Completion
<ol style="list-style-type: none"> 1. Check out CUREnet (https://serc.carleton.edu/curenet/index.html) for ideas on getting started 2. Sketch out a proposed schedule and write detailed student learning objectives; remember to include time for iteration and scaffold skill-building with research objectives 3. Hire a student teaching assistant 4. Find a colleague who can provide a sounding board 5. Prepare reagents and order materials needed 6. Contact local stakeholders who could support your efforts/apply for funding 7. Prepare assessments aligned with SLOs 	<ol style="list-style-type: none"> 1. Assign lab chores—brainstorm how to do this with your students 2. Keep a journal on how it’s going (both students and instructors) 3. Implement weekly data check-ins 4. Have students turn in materials request sheet for projected supply needs prior to conducting wet lab experiments 5. Ask TA to manage “Open lab” session 6. Be consistent in data collection/record-keeping 7. Come up with a plan “B” to switch directions if things aren’t working; flexibility and open communication are key 8. Require accountability from students in writing (research proposal, request for materials, data check-in) 9. Conduct pre-/mid-semester assessments 10. Allow time for revision/iteration 	<ol style="list-style-type: none"> 1. Communicate and present data to community of peers and faculty and/or stakeholders—may be in the form of a poster, paper, or oral presentation 2. Enter students into a college-wide research showcase or competition 3. Communicate with campus news or other media to highlight student achievements 4. Conduct post-assessments 5. Reflect on what went well, what needs changing

SLO = student learning objective.

important for successful outcomes in a CURE course, this may be used to leverage institutional support for a CURE. At a national level, funding opportunities may exist through the U.S. Department of Education, National Science Foundation, and U.S. Department of Agriculture. In particular, the NSF has IUUSE:EHR grants (Improving Undergraduate STEM Education: Education & Human Resources) that may be applicable for CURE projects. CURE proposals can also be used to obtain grant funding either through STEM educational funding or as evidence of the “broader impacts” section in a NSF research proposal (12). In addition to or in lieu of outside funds, cost can also be addressed through creating a collaborative CURE effort, either within or across departments and institutions. This will allow for the sharing of reagents, equipment, and space in order to reduce cost. Moreover, interdisciplinary collaborations may make the findings suitable for publication.

In the absence of outside funding or a collaborative community, individual instructors might consider a couple of additional options for offsetting cost. For example, a course fee could be charged to students enrolling in the course. While this would generate funds, it is not ideal to pass this cost onto the students. Another approach is to utilize publicly available datasets and conduct computer-based research to supplement wet lab experiments (30).

Fear of resistance

Student resistance. Fear of encountering student resistance, i.e., experiencing negative student reactions in class, has been cited as a barrier to innovation in STEM teaching (31), and CUREs are no exception. For example, faculty may fear that deviation from laboratory experiments with predetermined outcomes, as in traditional lab courses, will be met with frustration, and that students will react negatively to the unexpected nature of research (12). This may stem in part from the idea that students are conditioned to think that their grade in the course depends on whether they get the “right” answer, rather than understanding the scientific approach and process. Resistance could also be related to mismatches between faculty and student expectations of the course goals. For example, some students believe that they need to learn a wide variety of laboratory techniques in order to be prepared for STEM professions or graduate study and may therefore resist a course that applies fewer techniques with more depth and iteration (9).

One approach to mitigating student resistance is to engage students in key aspects of the CURE project, such as experimental design. Rather than distributing a defined protocol, consider providing opportunities for students to conduct a literature review and develop the protocol based on relevant articles. To minimize student frustration with literature searches, instructors could also implement a jigsaw assignment, where several articles are preselected by the instructor and shared among small groups in order to develop a protocol (32). This approach allows students

to take ownership of the of the process and more closely mirrors what they would experience in a research laboratory setting. Students can also be engaged in collaboration around troubleshooting. Class discussions can be devoted to determining what is working with the project and what needs to be improved. After brainstorming, students present their ideas to the class and a consensus is reached, with the instructor guiding the discussion. This approach allows students to be stakeholders in the project and can temper frustrations or concerns.

Moreover, it provides opportunities for instructors to be transparent about the nature of science and foster a collaborative classroom community. While not specific to the course content, use of affirming language to frame discussions and activities within the CURE will likely have a strong influence on student experiences and may reduce student resistance (33–35). Moreover, learning how to troubleshoot, reflect, redesign, and persist in the face of challenges are all practical skills that students will use in the real world, no matter what careers they pursue.

Faculty and institutional resistance. In addition to student resistance, some faculty may perceive judgment from their colleagues as another barrier to CURE development and implementation. For example, a common issue in implementing a CURE course is determining the balance between covering specific technical content and facilitating a research experience. This balance is a major topic in discussions among faculty, as many feel that the quality of a course is dependent on the amount of content covered. In addition, if colleagues are unfamiliar with the amount of time and energy involved in teaching a CURE course, this could lead to a devaluing in measuring teaching load. These may seem like significant hurdles to overcome when seeking faculty and institutional buy-in for your CURE course.

Interestingly, evidence of faculty or institutional resistance to CUREs is somewhat varied. An earlier study of a CURE in genomics reported lack of support from colleagues and the department chair as an important barrier to the successful outcome of the course (36). However, in a survey of faculty perspectives on developing and teaching CUREs, 68% of the faculty reported that teaching a CURE course contributed positively toward their tenure and promotion, indicating support among peers (12). In addition, 71% of the faculty mentioned receiving support through their department and/or administration upon taking on the challenge of teaching a CURE. Similarly, a national survey of biology faculty found that lack of institutional support was not considered a barrier by faculty respondents (37). So, while the perception may be that colleagues and institutions will not support the CURE effort, evidence of the opposite is also true.

One strategy to overcome this fear is to invite faculty and institutional stakeholders to your students’ CURE colloquium in the form of short talks or poster presentations. This strategy gives students the experience of disseminating their research to an audience while sharing your teaching innovations with your colleagues.

Fear of assessments

Shortlidge and Brownell (38) have extensively reviewed the existing literature on validated CURE assessment tools, and their paper provides an excellent resource for measuring the impact of a specific CURE. They bring up several points to consider before embarking on selecting and wielding a CURE assessment tool.

Is the instrument aligned with your specific CURE learning goals?

What student population and type of course was the tool used on?

How time-consuming will it be to implement this tool in your specific context?

There are many “ready-to-use” assessments for different phases of your CURE (14), but they may take some tweaking and modification for your course.

Identifying learning goals. Another challenge in developing a CURE may be that the instructor is unsure about how to measure the impact on student learning. Instructors must first articulate specific learning goals for the CURE. As with other STEM courses, the content and goals may vary when implementing a course for non-STEM majors,

first-year students, or upper-division majors students, who will enter the course with different scientific experiences and skills (15). Course goals can be addressed with the “backward design” approach. This approach begins with the establishment of goals for student learning, which then dictate course content and the development of assessments and class activities (39). Backward design will help in CURE implementation and determining the most appropriate assessment tools for the course (39, 40). As an additional resource, Irby et al. (41) provide a detailed and systematic approach for determining learning outcomes specifically for CUREs. Resources may also be available from institutional units and centers devoted to pedagogy and assessment (e.g., a Center for Teaching and Learning).

Student learning goals associated with CUREs can be broadly divided into scientific process skills and attitudes toward science. Scientific process skills may include understanding content, scientific communication, technical skill development, designing experiments, and analyzing data. Aspects of these can be evaluated with surveys (42) or with instruments for direct assessment. For example, the EDAT, expanded EDAT (E-EDAT) or Rubric for Experimental Design (RED) have been used to measure students’

TABLE 2.
Perceived barriers to implementing a CURE, solutions to address those barriers, and associated resources.

Challenge	Solution	Example	Reference(s)
Cost	Use materials already available	Research-based ecology lab course	(46)
	Collaborate across disciplines	Collaborative CUREs across chemistry, biochemistry, and neurobiology	(17, 47)
	Use publicly available datasets	Bioinformatics projects	(25, 30)
	Partnerships with high schools or with community stakeholders	Citizen science projects	(48)
Workload/Scale	Hire undergrad/grad TAs to help manage prep and implementation	Open lab hours managed by TA’s	(49)
	Start with a modular approach	Substitute a “cookbook” lab with an investigative one	(21)
	Change one section of the course	Implement a CURE as a pilot program	(20)
Measuring “success”	Develop assessments using backward design principles	Think about both research goals and pedagogical goals	(40)
	Many validated assessment tools exist for specific objectives	One assessment tool is not enough: design your own open-ended questions	(15, 38, 44, 45)
Student resistance	Give students sense of ownership	Students choose research question	(5)
	Make students aware of benefits	Employability/desirability of skills	(29)
	Foster a collaborative classroom community	Use of non-content “instructor talk”	(33)

abilities to design experiments (43). More affective learning outcomes may include attitudes about the nature of science, awareness of and interest in science-related careers, and persistence in STEM majors. In addition, assessments may indicate whether students have shifted their science identity or their perception of whether research is something they can see themselves doing (44, 45). Generally, open-ended written prompts or student reflective journals can be used to reveal student thinking and may provide insight into students' developing science identity, metacognition, and awareness of the process of science. Implementing a variety of assessment tools will reveal the diverse impacts of a particular CURE strategy, and help to inform the next iteration.

CONCLUSIONS

While there are challenges to developing a CURE, we hope that your fears have been overcome with some practical solutions. We have highlighted ways to succeed in dealing with issues of scale, cost, potential resistance, and assessment (Table 2) and provided a checklist as you embark on CURE development and implementation (Table 1). Our timeline (Table 1) highlights the importance of providing both students and instructors enough time to brainstorm and plan the experimental approach that will be taken. While the projects are underway, it is essential to build in enough time for troubleshooting and iteration, and a flexible attitude is key in order to change direction when needed. Finally, continuous assessment using existing tools and iteration is recommended to improve your course each semester. In the words of one of our students, "Even if it does not go as expected, continue to discover new things about your research project." The same can be said for your implementation of a CURE, so go ahead and take the plunge!

SUPPLEMENTAL MATERIALS

Appendix I: Online resources for CURE approaches

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