Perspective

JMBE Journal of Microbiology & Biology Education

Bridging Trade-Offs between Traditional and Course-Based Undergraduate Research Experiences by Building Student Communication Skills, Identity, and Interest

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Undergraduate research plays an important role in the development of science students. The two most common forms of undergraduate research are those in traditional settings (such as internships and research-for-credit in academic research labs) and course-based undergraduate research experiences (CUREs). Both of these settings offer many benefits to students, yet they have unique strengths and weaknesses that lead to trade-offs. Traditional undergraduate research experiences (UREs) offer the benefits of personalized mentorship and experience in a professional setting, which help build students' professional communication skills, interest, and scientific identity. However, UREs can reach only a limited number of students. On the other end of the trade-off, CUREs offer research authenticity in a many-to-one classroom research environment that reaches more students. CUREs provide real research experience in a collaborative context, but CUREs are not yet necessarily equipping students with all of the experiences needed to transition into a research lab environment outside the classroom. We propose that CURE instructors can bridge trade-offs between UREs and CUREs by deliberately including learning goals and activities in CUREs that recreate the benefits of UREs, specifically in the areas of professional communication, scientific identify, and student interest. To help instructors implement this approach, we provide experience- and evidence-based guidance for student-centered, collaborative learning opportunities.

KEYWORDS undergraduate research, course-based research, communication, interest, scientific identity, inclusive teaching, undergraduate research

PERSPECTIVE

Undergraduate research experiences play an important role in the development of undergraduate STEM students (1–4). Both traditional undergraduate research experiences (UREs) and course-based undergraduate research experiences (CUREs) offer benefits to student learning, including project ownership, collaboration with others, and authentic contribution to scientific research. These benefits are thought to lead to longer-term outcomes, including scientific identity and persistence in a discipline. However, UREs (typically operating with 1 to 2 students per mentor) and CUREs (often with 20 or more students per instructor) also differ greatly in scalability, access, intensity, and the research experience they create. These differences lead to key trade-offs faced by educators, raising questions about how to best provide research experience to all the students who seek it. To begin, we describe some of the key trade-offs between UREs and CUREs, and then we offer evidence-based recommendations on how to bridge those trade-offs through CURE curricula.

Trade-offs between UREs and CUREs

One key trade-off between UREs and CUREs is between scalability (the number of students reached) and intensity (the degree of apprentice-like training from an experienced researcher). At one end of this trade-off, traditional UREs include volunteer positions, paid hourly work, industrial internships, summer research fellowships, research-for-credit during the academic year, and summer research experiences for undergraduates (REU) programs. In these settings, one (or a few) select undergraduates typically work alongside a dedicated mentor (often a graduate student or postdoc) in a

Citation Burmeister AR, Dickinson K, Graham MJ. 2021. Bridging trade-offs between traditional and course-based undergraduate research experiences by building student communication skills, identity, and interest. J Microbiol Biol Educ 22:e00156-21. https://doi.org/10.1128/jmbe.00156-21.
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Received: 20 February 2021, Accepted: 21 April 2021, Published: 30 June 2021

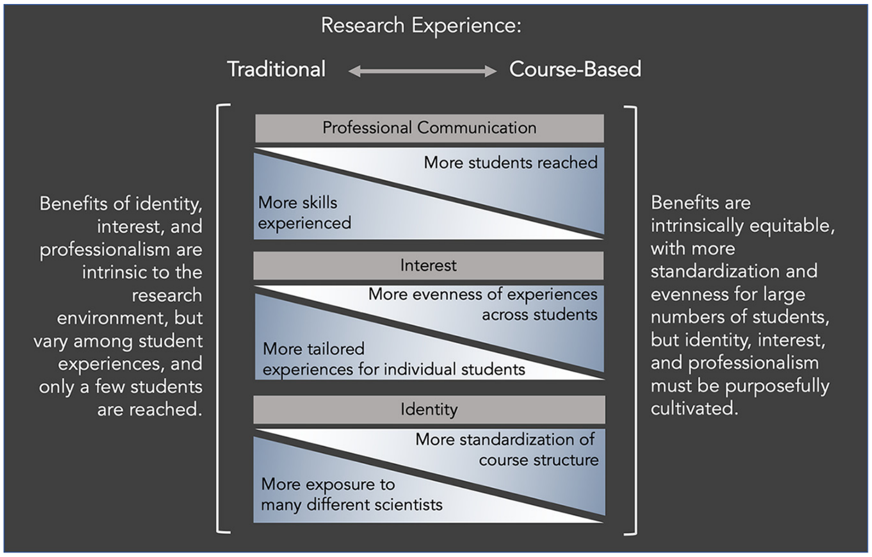

FIG 1. Trade-offs between traditional and course-based undergraduate research experiences. In traditional research experiences, the benefits of building professional communication skills, identity, and interest are intrinsic to the research environment, but these vary among student experiences and only a few students are reached. In course-based research environments, benefits are intrinsically equitable, with the potential for more standardization and evenness for large numbers of students; however, some aspects of identity, interest, and professionalism must be purposefully cultivated.

one-on-one mentorship model. Thus, UREs have low scalability and do not reach many students.

As a trade-off with scalability, URE students receive more intensive, longer training experiences, which are less likely in CURE environments. Because the environment of a URE is professional by nature, URE students are more likely to gain experience with professional communication skills that will help them succeed in future careers (Fig. 1, Professional Communication). In addition to working closely with an assigned mentor, students often interact with a diverse group of scientists. These interactions increase the chances a student will meet someone who can serve as a relatable role model, a key factor to increase their scientific identity (Fig. 1, Identity). Students may also be more likely to have a project tailored to their individual interests (Fig. 1, Interest). Overall, URE students typically receive in-depth scientific training, from reading the literature, framing scientific hypotheses, and running experiments, to interacting with other professional scientists and presenting their work at conferences. These experiences not only provide students with research involvement, but also career mentorship, sense of belonging, and scientific identity (1, 2). However, because UREs are difficult to scale up, these benefits may only be available to a limited number of undergraduate students.

On the other end of the trade-off, course-based undergraduate research experiences (CUREs) offer research in a many-to-one classroom research environment (Fig. 1). Because of this scalability, CUREs have been used as a means to increase retention in STEM while also providing more equal research opportunities for all groups of students—an idea that may translate to improved research equity and access among well-represented and underrepresented (UR) groups. (We note that specific language related to equity and inclusion is important and changing quickly in the STEM education literature (5, 6). Here, UR groups in STEM refers to women, persons with disabilities, African Americans, Latinx, American Indians or Alaska Natives, first-generation college students, and low-income students.) CUREs are often centered around semester-long research projects in which students collaboratively work on scientific questions of broad relevance. Throughout the semester, students seek novel discoveries, often iterating their work during trouble-shooting and replication (7). CURE students frequently demonstrate their knowledge through scientific presentations, writing, or other projects. In many CUREs, students use wet-lab scientific practices as a core tool to do experiments, but CUREs also often include computational research (8), collection and analysis of existing primary data (9), work with human subjects (10), and fieldwork (11). Many CUREs also include skills that are important to authentic research but do not directly involve data collection or analysis. For example, CURE students frequently design components of their research projects, collaborate with others, and communicate their findings (12).

Bridging the trade-offs

CUREs are clearly providing authentic research experiences and helping students develop interest in pursuing science, but because of the inherent trade-offs, CUREs are not yet necessarily equipping students with all of the experiences needed to transition into a research lab environment. In particular, CUREs differ from UREs in ways that could differentially impact student outcomes, particularly with respect to professional communication, identity, and interest (Fig. 1). While CURE students do not experience the "everyday" professional communication and relationships that URE students do, professionalism-building activities can be incorporated as part of CURE curricula. Likewise, CURE students lack access to the diversity of scientists encountered by many URE students, but the CURE instruction model has the potential to purposefully include identity-building activities at scale in a more standardized, equitable way. Finally, although UREs may be more tailored to an individual student's interest compared to the use of common projects throughout CUREs, CUREs may deliberately use interest-generating interventions to mediate this trade-off. Therefore, the purpose of this essay is to offer evidence-based guidance on how to work toward purposefully including these types of activities into existing and new CUREs, which will make CUREs more useful to students' professional development, equity, and inclusion in the sciences.

Elements developing professional communication, identity, and interest could be included in any science course, but we view the CURE learning environment as the most useful venue in which to encourage this type of learning. CUREs are generally set up with additional face time with the instructor and among students, which may provide for closer relationships in which students can more easily work through the nontechnical nature of these learning objectives. Additionally, CURE students will benefit from the synergy between doing research and the bolstering impacts of increased professionalism, identity, and interest. Just as URE students develop these areas alongside their primary research skills, we predict CURE students will benefit most when their personal and professional growth is synchronous with their research projects. Developing professional communication skills, identity, and interest may help students "buffer" the many challenging aspects of research that are not encountered in other course formats. For example, increased ability to communicate problems would help students when working through microbiological contamination issues; strengthened scientific identity will be useful when working through errors when writing computer code; and interest can help carry a student through the many mundane moments of data collection.

In the following sections, we seek to bridge the URE-CURE trade-off by proposing a deliberate approach to developing professional communication, scientific identity, and student interest in CUREs. We discuss how UREs provide students with valuable skills and insights that go beyond directly contributing to science, and we make a case that these elements need to be formally included alongside the research in CURE environments. Throughout the Appendix, we provide evidence-based guidance on how to do this for instructors and CURE program designers. These topics would fit well into many research-based courses, and they provide opportunities for student-centered, collaborative learning.

RECOMMENDATIONS

We suggest three general approaches that instructors can consider for CURE student learning goals that incorporate elements of traditional research experiences (Fig. 1). Although beyond the scope of the manuscript, UREs could likewise bring benefits of the CURE into the URE environment (such as providing additional structure, scaffolded learning goals, and research goals that can be achieved by undergraduates in a short time period).

Within each general recommendation area, we present specific options in the Appendix, including a guide for what to do, how to do it, and why it helps.

- For the first suggested learning goal (Develop Authentic Communication Skills), we discuss the many formal and informal forms of professional research communication, including those often overlooked in CUREs and other courses.
- For the second recommendation (Build STEM Identity and Sense of Belonging), we suggest ways that CUREs can formalize student identity building that is seen during UREs.
- For the third (Build Student Interest), we suggest evidence-based ways to strengthen students' personal and professional interest in science.

Throughout our recommendations, we take into account literature-supported evidence as well as our experiences as mentors in the research lab, as CUREs facilitators and instructors, and as academic and industrial researchers. As CURE instructors and traditional research mentors in the basic sciences (A.R.B. and K.D.) and CURE researchers (A.R.B., K.D., and M.J.G.), we are interested in how CUREs can benefit students' contributions to science and student development as researchers.

It is also important to emphasize that we do not view the suggested activities as a replacement for CUREs; rather, they are activities that complement existing CURE components. Overall, these types of changes will help students perform well while in CUREs, enable them to obtain post-CURE positions in UREs, and increase their success in their professional careers. While ongoing research aims to identify the essential components of CUREs for student learning, we view data collection, analysis, and research authenticity as key components of learning how to be a scientist. Together with CUREs' usual foci of experimentation, project planning, and data analysis, the suggested activities can enrich an overall research experience while building inclusive classrooms and better preparing students for careers in STEM. Overall, these recommendations are aimed to help ensure the benefits of course-based research extend beyond the course itself.

Suggested Learning Goal 1: Develop Authentic Com-munication Skills

Although CUREs and many traditional labs often focus on formal communication via lab reports and presentations, in practice, professional scientific communication includes a diverse array of written and verbal modes that vary from formal to informal (Table 1) and are important to the successful practice of science in academia, industry, and other organizations. CUREs can benefit from the inclusion of authentic activities that develop

TABLE 1
Authentic modes of communication that can be turned into assignments and assessments for building professional identity, competence, and confidence

Type of communication	Informal communication[a]	Formal communication[a]
Written	• Requesting a recommendation letter • Emailing a PI with interest of joining their lab group • Creating a meeting agenda when meeting with a PI or mentor • Maintaining a lab notebook • Sending a cover letter with a resume for a job application • Sharing scientific ideas over email • Posting scientific information to social media • Responding to others on social media	• Research manuscripts • Review articles • Patents • Technical reports within a company • Research proposals • Research statements • Personal statements • Diversity statements • Published articles for the scientific public • Conference abstracts • Poster content
Verbal	• Peer discussions, debates, and explanations • Group brainstorming • Chalk talks, depending on the context • Elevator pitches • Attending lab meetings • Visiting office hours • Informational interviews • Asking questions at scientific seminars • Addressing workplace issues (e.g., "Who keeps leaving the lab freezer door open?")	• Scientific presentations and posters • Behavioral job interviews[b] • Interviews for the news or podcasts • Science policy press conferences • Some chalk talks

[a]Here, we use the term "formal" to mean either communication intended for a more permanent record or communication that requires advanced preparation.
[b]Behavior-based interview questions are widely used in industry and health care to assess how candidates interact socially with others. Many question lists are readily available on the internet and include questions relevant to CURE experiences, such as "Tell me about a time you faced failure and how you dealt with it," and "Give me an example of a time a team or group you were on disagreed on an approach and how you handled it."

students' formal and informal communication modes. These forms of communication can also reinforce the acquisition of new knowledge, development of expertise, and strengthening of other scientific competencies. In academia, communication allows students to find a research lab to join, interview successfully, perform well once situated in a professional position, and to communicate their work. Communication is also valued in industry, where teamwork and professionalism are foci of performance reviews and management. Importantly, the learning and use of both formal and informal communication skills (Table 1) can be readily evaluated using authentic assessments through communication products created by students (13–15).

CUREs are especially well suited for student development of various communication skills, in particular informal communication, as an opportunity to better prepare students for any future career. As an easy-to-address example from our experiences and those of others (16), CURE students often get "stuck" after their CURE semester, unsure of how to (or lacking the confidence to) contact research professors to ask about undergraduate positions. A simple assignment during the semester, such as drafting emails that relate their CURE project involvement to their interest in a particular professor's lab, will help many students overcome this basic barrier to persistence.

While the slide- or poster-based presentation is a mainstay of many CUREs, formal verbal communication also includes occasions that demand quite different skills, including answering questions at job interviews, delivering chalk talks, responding to questions asked by the public or press, and presenting online (Appendix 1A). Likewise, formal scientific writing goes well beyond the usual lab reports that many CUREs and traditional labs require of students (Table 1). Learning how to write in a variety of contexts is important in both academia (e.g., research proposals, diversity statements, and review articles) as well as in industry (e.g., technical reports and patents). Although formal writing is often incorporated into CUREs and traditional labs, it is often limited to writing lab reports and presenting final projects.

See Appendix 1A for specific guidance, activities and evidence on "Informal Written Communication, Informal Oral Communication, Formal Written Communication" and "Formal Oral Communication."

Suggested Learning Goal 2: Build STEM Student Identity and Sense of Belonging

One way that CUREs often differ from UREs is that during UREs students get to interact with many different scientists while also learning the scientific research process. Whether having lunch with the grad students, discussing how to apply to grad school, overhearing discussions about peer review, going on lab outings, or talking about life during weekly meetings, mentored experiences provide ample opportunities for students to more wholly become and identify as part of their lab's research community. While these particular experiences are unlikely be replicated at scale in a CURE, CUREs have the benefit of reaching more students and reducing barriers to doing research, especially when they are taught as introductory level courses (3). This is critical because many undergraduate students leave STEM programs, with underrepresented students leaving at higher rates (17, 18). One factor that can deter persistence is a lack of science identity, which refers to the ability to see oneself as a scientist and is linked to a sense of self-efficacy (19). Conversely, underrepresented students who have a sense of science identity are more likely to choose a STEM career (20).

Identity development has many factors that can be cultivated in a course-based environment and in a student-centered fashion. A student gains science identity when they develop science competencies by learning new skills and doing science, which are already key components of both UREs and CUREs. Another factor that influences science identity is the receipt of mentorship from more experienced scientists. Although developing individual mentoring relationships is out of scope for most CUREs, our classrooms can still be a place where students learn about mentee benefits, boundaries, and responsibilities. With this knowledge, students will be better informed about what to expect when later pursuing research outside class. Seeing oneself as a mentee, and more generally a learner and trainee, may also help strengthen scientific identity, as it could relieve the burdens of feeling expected to immediately perform at an expert level or to never make mistakes. See "Learning About Mentee Roles" in Appendix 1B.

Other factors can diminish scientific identity, and these must be actively considered in course design. In particular, lack of diversity in science can leave underrepresented students feeling isolated or that they need to change themselves to fit in (21). Furthermore, racial stereotypes can result in the negative consequences associated with stereotype threat (22). Finding ways to increase diverse perspectives with outside resources can be especially useful in providing students with science role models and representation. See "Learning About a Diverse Array of Scientists' Lives and Research" in Appendix 1B. For instructor-centered tips on building every-day inclusivity—a concept closely related to identity—see "Inclusive Classroom Practices" in Appendix 1B.

While identity-building activities would also be well-suited to non-CURE (and even non-laboratory) teaching environments, we hypothesize they will be most effective in CUREs, where students are simultaneously developing primary scientific identity by directly conducting science, and where students' strengthened identity will help buffer the difficult, challenging, and more mundane moments of the research process.

Suggested Learning Goal 3: Build Student Interest Related to All Stages of Research

One of the central hypotheses for why CUREs are effective at engaging and preparing students is that they empower students to contribute directly to broadly relevant scientific questions (7, 12, 23). Different CUREs investigate and generate new knowledge across a wide variety of contexts, including the study of human microbiomes (8), the discovery of new antibiotics (24), the characterization of new genomes (25, 26), determining the prevalence of antibiotic resistance (27), and observing animal behavior (28). The more instructors can pair student learning with topics relevant to students' lives or research, the more CUREs might provide motivation for learning and increase students' interest, confidence, persistence, and ownership (23, 29). Even outside a direct research experience, interest or perceived usefulness may lead to increased retention in STEM (30).

Many students arrive at a course with preexisting interest in the course topic, which is positively associated with topic mastery goals and negatively associated with work and performance avoidance goals (31). However, many CUREs, which are anchored in an authentic research program, tend to have very specific, niche topics that may not be broadly appealing to all students without learner-appropriate generalization. (For example, while author A. R.B. is quite excited about her CURE's theme of antagonistic pleiotropy in bacterial evolution under phage selection, students may not be prepared to find this topic immediately appealing to their personal and professional interests.) Therefore, establishing situational interest, or relevance, for course scientific content through other means is important for increasing engagement in a course and its associated STEM major (31, 32). For instance, introducing A.R.B.'s CURE in terms of important considerations for phage therapy and other applications has helped attract student interest even before the first day of class. Ideally, when students see the relevance of their learning, their overall (personal) interest will also be increased. Relevance can be established in many ways that may appeal differently to individual students. Belova et al. (33) identify four categories of scientific relevance, and we use this framework to think about various ways interest can be established with respect to CURE content (Table 2).

See Appendix 1C for options and activity outlines to help instructors identify strategies that may work for their courses, including: (i) Student-Generated Relevance; (ii) Instructor-Guided Utility Generation; and (iii) Collaborative Instructor-Student Learning Through Case-Based Activities. As with our other recommendations, these suggestions could work well in any science course, but are again particularly applicable for CUREs, where students may encounter a niche area of science for an entire semester.

SUMMARIZING REMARKS

Both UREs and CUREs provide important professional preparation for undergraduates in the sciences, but they differ

TABLE 2
Forms of scientific relevance, where CURE students may prioritize different categories of relevance, depending on personal and professional goals, interests, and course topics

Category[a]	Definition[a]	Importance for CURE Students
A, Employability	Gaining skills for further education and eventual employment	Demonstrating laboratory, analytical, and communication skills
B, Innovation	Suggesting improvements to authentic issues in a field of practice outside coursework	Contributing work that has broad relevance and novelty
C, Media literacy	Understanding and generating media content	Understanding and generating primary literature; communicating work to a broad audience
D, Ethics	Development of responsible global citizens and professionals	Understanding the social context of one's work or course content; conducting ethical research and course work

[a]Adapted from reference 33. Belova et al.'s Category D was originally termed "sustainability," which we have renamed "ethics" to be more inclusive of the many ideas captured in their original discussion and our implementation.

along a challenging trade-off curve between scalability and intensity of student professional experience. While UREs offer intensive, longer-term training in a professional environment, CUREs have the benefit of reaching more students while still contributing novel scientific information to the broader scientific community. For the last several years, we have been collectively thinking about how to enrich CUREs to better prepare students as UREs do. Sudden shifts in instructional and mentoring practices during the pandemic of 2020 catalyzed our thinking about undergraduate research goals during and beyond disruptions to teaching and research. This thinking led to some of the suggestions in this essay, along with the realization that these practices would be well applied in the long term as research and learning returns to in-person venues.

Throughout the Appendix, we identified evidence-backed activities that can fit well into current and new CURE courses. We also propose that such activities will be more useful to student learning and engagement the more that they are interconnected, similar to the current research arc of many activities students already encounter in CUREs (12, 34). Whether implemented individually or as a group of activities, we stress that using backward design with a focus on learning objectives will be the best way to guide course design around student needs (35). Instructors should consider our suggestions as a starting point to identify new learning objectives and then build from there to incorporate new learning activities.

Although there are many ways to enhance a CURE, we also underline that core CURE elements include student ownership in projects with research authenticity, whether that involves making discoveries in the lab, addressing theory with computational work, or reanalyzing existing data to address a new scientific question. Helping students to develop professional communication skills, scientific identity, and interest in STEM will help them perform in their CUREs, and it will prepare them to find and succeed in their next scientific experiences. Toward that end, we hope that some of the ideas presented here will enable CURE students' future contributions to the world of scientific knowledge.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, DOCX file, 0.03 MB.

ACKNOWLEDGMENTS

This work was supported by the National Science Foundation Division of Undergraduate Education through I-USE grant number 185610 and RAPID grant number 20276598 and the Howard Hughes Medical Institute through grant number 52008128.

We thank Mike Blazanin, Julia Gill, Scott Freeman, and Ben Kerr for useful comments on an earlier version of the manuscript.

We declare no conflicts of interest.

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