Course-based Undergraduate Research Experiences: Current knowledge and future directions[1]

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Abstract

Course-based Undergraduate Research Experiences (CUREs) have emerged in recent years in response to studies showing the benefits of undergraduate research internships and to national calls to engage many more STEM undergraduates in doing research. The purpose of this paper is to summarize the state of knowledge about CURE instruction, including shortcomings in the knowledge base and recommendations for future research and practice.

CUREs are distinctive as learning environments

versus other meaningful products remains an area of debate.

udent-, faculty-, and institution-level goals have driven CURE development,
the life sciences and chemistry. These goals include the desire to improve students'
nd success in STEM and in college, to make research accessible to a larger and

UREs and because the research that students do in CUREs occurs in the context of a credit-bearing course. I define CUREs as learning experiences in which *whole classes of students address a research question or problem with unknown outcomes or solutions that are of interest to external stakeholders.*

I will avoid using the term "authentic" because I believe the term "research" sufficiently captures the aim of CUREs to engage students in making discoveries and contributing to a broader body of knowledge. In addition, the term "authenticity" carries many meanings that have not been clearly defined or delineated in studies of CUREs or UREs (Alkaher and Dolan, 2014; Buxton, 2006; Chinn and Malhotra, 2002; Rahm et al., 2003; Roth, 2012). For example, in Rahm and colleagues' (2003) study of a high school student-teacher-scientist partnership, participants' notion of what made a project authentic was emergent rather than static or predetermined.

What is a CURE? The first published description I could find of research being embedded into an undergraduate course was from Fromom.sea. s in the departomnt. there

n an explosion in the developomnt of CUREs, particularly in biology and chemistry, and scientific community alike (Alaimo et al., 2014; Auchincloss et al., 2014; Hatfull et al., 2006; Spell et al., 2014). T

Faculty buy-in to CURE instruction may depend on the likelihood that students will produce results that are publishable, or can at least move research forward. Several studies of CUREs note science publications as important outcomes (e.g., Full et al., 2015; Hatfull et al., 2006; Jordan et al., 2014; Leung et al., 2015; Ward et al., 2014). In addition, studies of faculty undergraduate careers (Alkaher and Dolan, 2014; Auchincloss et al., 2014). Introductory-level CUREs in particular have been championed for their potential to “level the playing field” by functioning as a gateway to UREs. Bangera and Brownell (2014) argue that CUREs can increase inclusion and broaden participation in STEM because they serve as an avenue for students to

Local programs. A handful of institutions have developed internal CURE programs that serve hundreds of students by utilizing numerous CUREs, such as the Center for Authentic Science Practice in Education at Purdue University (https://www.purdue.edu/discoverypark/caspie/; Russell et al., 2010), the Freshman Research Initiative (FRI) at University of Texas at

close connections with industry and the availability of non-academic internships in these disciplines. Undergraduate research in disciplines such as physics, math, astronomy, and computer science still appears to occur primarily through internships, although the Center for Undergraduate Research in Mathematics has supported small teams doing faculty-mentored math research for pay (Dorff, 2013). Several examples of course-based math projects are described in "Directions for Mathematics Research Experiences for Undergraduates" (Peterson and Rubinstein, 2015), but these are generally characterized as inquiry-based learning (Laursen et al., 2011), and aim to develop students' mathematical thinking skills and preparation to participate in UREs. The dearth of undergraduate involvement in math research has been attributed to lack of student capabilities at the undergraduate level, the nature of mathematics as a discipline, and historical lack of funding for undergraduate research in math, although NSF has funded many taking other courses in the

There is general agreement that mentoring college students can improve their success in terms of retention and satisfaction in college, the grades they earn, and their social integration into academic and disciplinary settings (Crisp and Cruz, 2009; Gershenfeld, 2014; Jacobi, 1991). Given that many CUREs aim to achieve these outcomes for students, there is a clear need to examine research on mentoring in general and on mentoring

CURE Outcomes

Overview. Given the focus on CURE instruction as a mechanism for making the benefits of UREs available at scale, there is great interest in the outcomes of CUREs for students and faculty alike. In a recent essay, Corwin and colleagues (2015a)

Table 2. Support for CURE outcomes based on a review of relevant CURE literature. Green shading indicates probable outcomes, yellow shading indicates possible outcomes, and gray shading indicates proposed outcomes. (Corwin et al., 2015a)

Outcome	CURE References
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible] *et al.*, 2014
[illegible]	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]

Theoretical framework.

The widespread use of project-specific assessments raises an important question about the value of measuring content knowledge gains from CURE instruction. Given that one of the goals of CUREs is to develop students' expertise as scientists, and that one always has limited time and resources for assessment, it may be that developing science practice skills is a more important outcome to measure. In addition, it may be less informative to examine what knowledge students gain and more informative to examine how students use the knowledge that

Affective, attitudinal,

notebooks, presentations, publication-style papers) (Fukami, 2013; Hatfull et al., 2006; Kloser et al., 2011). This advice is based largely on the personal experience of people in the trenches rather than emerging from theoretical or empirical evidence. Fukami (2013) also recommends that instructors have expertise in the study system, but there has been no systematic investigation of the level or type of scientific or pedagogical expertise necessary to teach a CURE effectively. Future research should examine how faculty learn to teach CUREs effectively, including what kinds of content knowledge, pedagogical knowledge, and pedagogical content knowledge are needed to teach CUREs well.

Almost all studies of CUREs (and UREs) have treated them like a black box – a singular treatment that differs from traditional or inquiry courses in ways that are hypothesized to affect student outcomes. Only recently has there been any empirical work to identify the design features of CUREs that make them distinct from other learning environments and effective for students. One feature for which there is a reasonable level of evidence is the idea of ownership (Hanauer and Dolan, 2014; Hanauer et al., 2012), or the extent to which a student not only feels personal responsibility for the project but also identifies with the project in some way. Studies of levels of ownership students develop in traditional courses, UREs, and CUREs indicate that high levels of ownership may be unique to CUREs (Hanauer and Dolan, 2014; Hanauer et al., 2012). Corwin and colleagues (2015b) have also been able to distinguish CUREs from traditional courses using measures of opportunities for students to make broadly relevant discoveries and engage in iterative work. A next step in research on CUREs will be developing and testing models of how design features relate to student outcomes curriculum design strategies can be used to address these questions (Wiggins and McTighe, 2005).

How will research progress be balanced with student learning and development? Ideally, students learn and develop in the process of moving the research forward. Sometimes the processes for achieving student outcomes and achieving research outcomes are not tightly aligned. For example, multiple rounds of data collection are often necessary to move research forward, but students will not learn anything new from

have only recently been the focus of study, there has been little if any investigation of how CUREs evolve scientifically, including strategies for shepherding CUREs through scientific transitions. Thought should be given as to when and how research learning tasks should evolve in order for the research to progress and for new cohorts of students to have opportunities to make discoveries.

Challenges of CUREs

There has been little systematic study of the challenges associated with developing, implementing, and sustaining CUREs. Lopatto and colleagues (2014) surveyed a national group of faculty from diverse institutions about the challenges they experienced in implementing GEP. Faculty who persisted in implementing the program reported that the most significant challenges were making the experience fit in the undergraduate curriculum of their institution, concerns about teaching assistantship support, and concerns about class sizes being too large to implement the project well. These same faculty reported that the central support system offered by GEP, including follow-up professional development, a central website with information and resources, supportive colleagues, and staff support for computing, troubleshooting, and instruction, helped mitigate the challenges. The concerns about curriculum fit co-12(c)lleA1c3m trlT(t)-2(s)6()-4(d i)-26(lleA1Bd

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