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Implementing and Evaluating a Course-Based Undergraduate Research Experience (CURE) at a Hispanic-Serving Institution

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ABSTRACT

We are examining the impact of a course-based undergraduate research experience (CURE) at a land-grant, Hispanic-serving institution in the southwestern United States. Students in our CURE completed one or two extended research projects over a single semester. Our CURE enrolled a high proportion of underrepresented minority students (70.3%), including 60.2% Hispanic students. One year after CURE completion, 31.5% of CURE students had graduated with a STEM degree, and 54.3% were enrolled in a STEM major. Pre- and postcourse surveys of indicators of persistence including scientific self-efficacy, scientific identity, valuing scientific community objectives, and intention to persist showed positive shifts. Impacts on STEM persistence have implications for the role of our CURE in diversifying the STEM pipeline, particularly for students historically underrepresented in STEM.

Keywords: CURE, undergraduate research, STEM persistence, STEM retention

Introduction

Background

Course-based undergraduate research experiences (CUREs) are increasingly used on a national scale to enhance STEM persistence and to retain diversity in the STEM pipeline (e.g., Auchincloss et al., 2014; Bangera & Brownell, 2014; Corwin, Graham, & Dolan, 2015). CUREs are intended to provide authentic and early research experiences to students at scale, engaging more (and potentially more diverse) students than traditional mentored research experiences. Students in CUREs work on extended (e.g., semester-long) projects to address a research question for which the answer is unknown. CURE projects are also relevant to the broader scientific community (beyond the context of the course) and have the potential to produce publishable results (Auchincloss et al., 2014). By offering an authentic research experience, CUREs can promote STEM interest, motivation, and persistence, potentially fostering a well-trained, diverse, and innovative STEM workforce (e.g., Bangera & Brownell, 2014; Elgin et al., 2016).

There are many open research questions about CUREs, particularly how specific aspects of CURE design contribute to specific outcomes (Auchincloss et al., 2014; Corwin et al., 2015; Shortlidge & Brownell, 2016). While many reports of CUREs have noted a variety of positive outcomes (see Corwin et al., 2015 for a review of CURE outcomes), it is still not known if all outcomes are achieved consistently across all CUREs, or whether outcomes vary based on student-specific factors (e.g., academic level, racial/ethnic background), characteristics of the institution, or aspects of the CURE itself (Corwin et al., 2015; Dolan, 2016). For example, in a recent study, Corwin et al. (2018) demonstrated that discovery, iteration, and collaboration had positive impacts on student intentions to pursue a research career, and these were mediated by project ownership. This highlights the importance of CURE design features and begins to provide a mechanism by which design features influence student outcomes. It remains to be determined whether the same mediators will drive outcomes in other CUREs.

We are beginning the fourth year of implementation of a CURE at a land-grant, Hispanic-serving institution in the southwestern United States. We have documented the characteristics of the students who have participated in our CURE to determine the extent to which our CURE is serving our diverse population of students. We have also evaluated the impact of our CURE on student attitudes that have been linked to STEM persistence, and the one-year post-CURE outcomes of CURE students. These baseline data will contribute to our understanding of the impact of the CURE at our institution and will allow us to begin to generate models and test hypotheses about *how* our CURE is contributing to specific outcomes. This study has the potential to contribute to the growing body of literature on the impacts of CUREs, particularly in diverse student populations.

Literature Review

The Problem With STEM

It is well known that students leave STEM at high rates, and that students who are traditionally underrepresented in STEM disciplines leave at higher rates. This means that the STEM workforce does not reflect the diversity of the nation, and that underrepresented groups (URMs) remain underrepresented in STEM (National Science Foundation, 2017; President's Council of Advisors on Science and Technology [PCAST], 2012). While there are myriad factors contributing to this problem, we are focusing here on access to research experiences. Discipline-specific research experiences can be transformative for students in terms of persistence in the STEM pipeline, but all too often occur late in a student's academic career, or not at all (PCAST, 2012).

Undergraduate Research Experiences

Undergraduate research experiences have positive impacts on student retention and persistence in STEM (e.g., Frantz et al., 2017; Jordan et al., 2014; Lopatto, 2004; PCAST, 2012; Villarejo, Barlow, Kogan, Veazey, & Sweeney, 2008). These experiences have traditionally taken the form of research apprenticeships, in which students work as part of a faculty member's research group. While research apprenticeships have been shown to be effective in increasing self-efficacy for scientific research, increasing scientific identity, reducing science anxiety, producing gains in thinking and working like a scientist, understanding the research process, and understanding how scientists work (e.g., Frantz et al., 2017; Hunter, Laursen, & Seymour, 2006; Lopatto, 2004), they are limited in terms of their capacity to serve a substantial fraction of STEM-interested students (e.g., Brownell et al., 2015; Frantz et al., 2017; Jordan et al., 2014). There may also be barriers to participation for students traditionally underrepresented in STEM (Bangera & Brownell, 2014). For example, the fact that many mentored research apprenticeships are directed at advanced students, and that most attrition in STEM degrees occurs in the early stages of student careers, means that many students leave STEM before encountering these engaging opportunities (PCAST, 2012). First-generation college students and their families may be unaware of undergraduate research opportunities, may be unaware of the importance of undergraduate research experiences, or may even consider undergraduate research to be a distraction from coursework (Bangera & Brownell, 2014). For students of lower socioeconomic status who rely on paid work to support their studies, volunteering in labs to gain research experience may not be economically feasible. CUREs offer solutions to these barriers, particularly if they are required of all students at the introductory level (so everyone takes them as part of their studies and the course is included in their tuition) (Bangera & Brownell, 2014).

CUREs have the potential to reduce barriers to participation and make research experiences more inclusive by providing access through course enrollment (in some cases required course enrollment) rather than an application process and by targeting students earlier in their undergraduate careers (Bangera & Brownell, 2014; Brownell et al., 2015; Elgin et al., 2016; University of Texas at Austin, 2018). As noted by Elgin et al. (2016), CUREs can transform research experiences from experiences of privilege to a "pedagogical necessity."

What Defines a CURE?

CUREs are laboratory-based courses in which students engage in authentic ("real") research (Auchincloss et al., 2014; Bangera & Brownell, 2014; Jordan et al., 2014; Shortlidge & Brownell, 2016). CUREs are characterized by five critical factors (Auchincloss et al., 2014). These include (1) the use of scientific practices, (2) discovery (i.e., the outcomes of the research are unknown to both students and the instructor), (3) broadly relevant or important work (i.e., the research has impact beyond the classroom, including other researchers or community stakeholders), (4) collaboration, and (5) iteration (Auchincloss et al., 2014).

Types of CUREs

There are several models of CUREs, each distinguished by the nature of scientific research questions and how they are generated. In some CUREs, the research question is independent of the research interests of the instructor (Brownell et al., 2015; Olimpo, Fisher, & DeChenne-Peters, 2016; SEA-PHAGES, n.d.; Small World Initiative, n.d.). In these CUREs, students ask research questions using model systems (e.g., baker's yeast, marine copepods [a type of zooplankton], bacteriophages [viruses that infect bacteria], or bacteria isolated from local soils) that are relatively straightforward and low-cost, making them feasible at a variety of institutions, including primarily undergraduate institutions and two-year colleges. Some of these CUREs have been developed for national distribution and include training workshops for instructors, as well as laboratory protocols and ordering information for necessary equipment and supplies (SEA-PHAGES, n.d.; Small World Initiative, n.d.). These "off-the-shelf" CUREs are thus relatively straightforward to set up, facilitating broad implementation at low cost. These CUREs all include discovery by allowing students to discover novel bacteriophages or antibiotic-producing bacteria (SEA-PHAGES, n.d.; Small World Initiative, n.d), ask novel questions about the evolution or life history of marine plankton (Olimpo et al., 2016), or examine the impact of previously uncharacterized mutations in a protein that is altered in at least 50% of all human cancers (Brownell et al., 2015).

Other CUREs focus on an ongoing research question related to the research program of the instructor (Bascom-Slack, Arnold, & Strobel, 2012; the Freshman Research Initiative at the University of Texas at Austin [University of Texas at Austin, 2018]; the Python Project [Harvey, Wall, Luckey, Langer, & Leinwand, 2014]). In addition to providing research opportunities for students, this model has the potential to advance the faculty member's research program and increase its research capacity (Brownell & Kloser, 2015; Fukami, 2013; Kloser, Brownell, Chiariello, & Fukami, 2011), and also provides an opportunity for research-focused faculty to become more engaged in teaching (Brownell & Kloser, 2015).

Which CURE model is "better" in a given situation will depend on the desired outcomes in terms of students, faculty, and the institution. Some of the impacts of each CURE model on students, faculty and institutions are noted in Table 1.

Stakeholders	**Impacts of Researcher-Independent CUREs**	**Impacts of Researcher-Driven CUREs**
Students	(+) More time for iteration, which may be a key feature in ownership, leading to research career intention (Corwin et al., 2018) (+) Potential for greater opportunity for students to generate their own (independent) research questions (-) Instructor(s) may not be experts in the specific research area/question (so students may not receive same level of expert mentorship/guidance)	(+) Expert mentorship on the specific project (Fukami, 2013; Kloser et al., 2011) (+) Enhanced likelihood of scientific publication, given vested interest of instructor (Fukami, 2013)
Faculty	(+) Opportunity to facilitate a discovery-based CURE, which is often more enjoyable than traditional STEM courses (Dolan, 2016) (-) Faculty/instructor may not be an expert in the scientific area and may lack confidence	(+) Teaching and research become synergistic (Fukami, 2013; Kloser et al., 2011) (+) Teaching can contribute to research productivity and publications (Fukami, 2013; Harvey et al., 2014; Kloser et al., 2011) (+) Course can recruit undergraduate researchers to faculty research team (Dolan, 2016)
Institution	(+) Enhanced retention and persistence of students in STEM (Auchincloss et al., 2014; Bangera & Brownell, 2014; Dolan, 2016) (+) Not tied to any one researcher, the course is a departmental resource, which may contribute to sustainability of the course over time (-) Faculty/instructor may not be an expert in the scientific area, requiring training and external technical support (Jordan et al., 2014)	(+) Enhanced faculty buy-in to teaching (as teaching and research can be synergistic) (Fukami, 2013) (+) Enhanced retention and persistence of students in STEM (Auchincloss et al., 2014; Bangera and Brownell, 2014; Dolan, 2016) (+) Enhanced opportunities for research-active faculty to become involved in teaching and have expanded interactions with students (Harvey et al., 2014)

Table 1. CURE models and impacts on key stakeholders.

CURE Outcomes

Many outcomes have been associated with CUREs, and Corwin et al. (2015) have summarized and categorized them as probable, possible, or proposed. Student outcomes resulting from CURE participation appear to be similar to those resulting from mentored research experiences, and in fact, students participating in the SEA-PHAGES CURE have higher self-reported learning gains across a wide range of skills compared to students participating in a summer mentored research experience (Jordan et al., 2014). A sampling of student CURE outcomes is presented in Table 2, and other sources provide more comprehensive reviews (e.g., Corwin et al., 2015).

Relationship Between PBL and CUREs

As is probably apparent, a CURE could potentially be considered an "extreme" form of PBL, in which the driving question/problem is an authentic research question and the solution results in discovery of new (to everyone) knowledge. Despite the various models of PBL implementation, it is generally agreed that features thought to be important for PBL problems include being open-ended, authentic, ill-structured, and requiring collaborative learning to solve (e.g., Ertmer & Glazewski, 2018; Hung, 2016; Pierrakos, Zilberberg, & Anderson, 2010).

The idea that research questions can serve as the foundation of PBL problems has been explored by Pierrakos, Zilberberg, and Anderson (2010) in a survey of undergraduate engineering students who were participating in research experiences. The researchers were interested in determining the extent to which the research questions that the students were investigating (e.g., in a laboratory or industry setting) were suitable for adaptation for use as classroom PBL problems. Given the nature of the research questions identified in their survey, Pierrakos, Zilberberg, and Anderson (2010) concluded that the research questions "meet the criteria for ideal PBL problems" (p. 55). In fact, their vision is to adapt research-based problems into a PBL context to begin to introduce a stronger research model into a nonlaboratory classroom environment (Pierrakos, Zilberberg, & Anderson, 2010).

Allchin (2013) has also characterized key features of PBL and case-based learning (CBL). While there is an acknowledgement of "boundary disputes" when characterizing these approaches, there is also a recognition of key (and common) features of PBL and CBL. These include student-centeredness, contextualization of the content, learning to think and to understand the process of science and how science is carried out (Allchin, 2013). Of these features, contextualization (in a real research question), learning to think, and learning about how science is practiced are all also shared with CUREs. Allchin (2013) also notes that PBL problems can be structured so that students generate new knowledge (at least to them). As noted above, CUREs are intentionally designed for new knowledge generation (new to students, instructors, and the field), so they may be considered the ultimate knowledge-generating problems or cases. And if translated to a classroom (rather than a laboratory) environment, knowledge-generating cases may be critical in students' developing an enhanced understanding of scientific research (Allchin, 2013).

In summary, CUREs and PBLs differ fundamentally in that CUREs are laboratory (or field) based, with students carrying out experiments to discover completely new knowledge, and PBL is more typically a classroom-based strategy, but still frequently relies on knowledge generation by students. These approaches share common features as noted above, including contextualization in the real world, open-ended and potentially "messy" questions, and collaboration.

Reported CURE Student Outcomes	Selected References
Persistence (1st to 2nd year)	Jordan et al., 2014
Increased probability of graduating with a STEM degree	Rodenbusch et al., 2016
Increased probability of graduating within 6 years	Rodenbusch et al., 2016
Increased content knowledge	Olimpo et al., 2016; Shaffer et al., 2014
Enhanced data analysis and interpretation skills (both actual and student self-reported)	Brownell et al., 2015; Jordan et al., 2014
Self-reported gains in research skills	Jordan et al., 2014; Shaffer et al., 2014
Enhanced scientific self-efficacy, scientific identity, scientific thinking	Brownell et al., 2015; Frantz et al., 2017

Table 2. Summary of reported CURE student outcomes with selected references.

Given the authentic practice of science and the discovery nature of CUREs, CUREs are likely to be most effective when the desired student outcomes include exposure to hands-on science and scientific research, and the resources permit a laboratory experience at scale. On the other hand, as posited by Pierrakos, Zilberberg, and Anderson (2010), research questions such as those addressed in CUREs can provide the "fodder" for the development of classroom-based PBL problems, or even cases for CBL (Allchin, 2013; Ertmer & Glazewski, 2018).

Here we evaluate the impact of our CURE on our population of students, particularly persistence in STEM enrollment and psychological predictors of STEM persistence, specifically scientific self-efficacy, scientific community, scientific identity, and intention to persist (Chemers, Zurbriggen, Syed, Goza, & Bearman, 2011; Estrada, Woodcock, Hernandez, & Schultz, 2011). These are likely to be important mediators and predictors of long-term persistence in STEM (Chemers et al., 2011; Corwin et al., 2015; Corwin et al., 2018; Estrada et al., 2011). These short- and medium-term outcomes also allow us to evaluate our CURE and implement revisions in instruction or structure if these outcomes are not being met (Corwin et al., 2015). More broadly, this work contributes to a call for the use of common metrics (particularly the established instrument of Estrada et al. [2011] with information on reliability and validity), as well as characterization of many diverse CUREs (Corwin et al., 2015; Dolan, 2016), which will eventually lead to a greater understanding of how CUREs can best be implemented with diverse populations of students to achieve important student outcomes (Auchincloss et al., 2014).

Methods

We used a case study design to address our research questions (Heale & Twycross, 2018; Merriam, 1998, p. 39). As noted by Heale & Twycross (2018), there is no single definition to describe the case study research design. However, this design is generally acknowledged to provide a careful exploration of a particular situation, in a particular context, without an expectation of generalizability. In our case, we are seeking to better understand our CURE and specific impacts on our diverse population of students, essentially a "what is" question (a description of what is happening to students during and after our CURE) (Bass, 1999). Once we have a better understanding of *what* is happening, we can begin to develop and test hypotheses about *why* it is happening, including identifying critical factors that may be greater or lesser contributors. Thus, this case study is the first step toward a better understanding of our CURE, and it can suggest additional avenues for exploration and course refinement.

Research Questions

1. What are the one-year post-CURE outcomes for STEM enrollment and completion?
2. What is the impact of our CURE on shorter-term psychological predictors of STEM persistence in our students?

Context

We teach at a land-grant, Hispanic-serving institution in the southwestern United States. Many of our students are first-generation college students with a low socioeconomic status. We used external funding to develop a CURE in the Biology Department. Our objectives for offering the CURE align with national CURE objectives:

- Provide an early-stage authentic research experience for STEM-interested students
- Increase interest in and motivation for STEM
- Provide an early entry-point into undergraduate research (e.g., start with the CURE, then move to internships or research apprenticeships)
- Support and increase diversity in STEM

Our CURE is offered as a 3-credit upper division (300 level) laboratory course, with no separate lecture or recitation sections. The course meets twice a week for a total of six hours each week. The course meets in a renovated teaching laboratory that is equipped as a molecular biology research space and can hold up to 24 students. The only course prerequisite is our cellular-based introductory biology course and its corresponding lab. This means that students can register for the CURE as soon as they have completed their introductory biology course work. The CURE satisfies a biology degree requirement for an upper division laboratory course, but is not required for the biology major. The vast majority of CURE students to date (~80%) have been biology majors, and over 90% have been majors in the life sciences. To date, the CURE has been offered eight times (including the current spring 2019 semester, in progress) by five different instructors. Enrollments have ranged between 14 and 22, with an average of seven unfilled seats per offering.

Our CURE model gives ownership of the design and format of each iteration to the instructor. Instructors develop the general research topics/questions and details of course logistics and organization. Despite the instructor-driven focus of each iteration, we work to preserve the elements of a CURE (Auchincloss et al., 2014) and our overall CURE objectives across all iterations by discussing these objectives with instructors during the course design phase, and by providing them materials from previous iterations of the course (which they are free to modify or replace entirely). Below we provide a general description of our CURE based on the experience of two instructors: the instructor with the most CURE experience (three semesters, including the "founding" semester of our CURE) and the instructor with the most recent past CURE experience.

Despite the differences in research focus (described below), each of these instructors implemented several common elements in their CUREs. Both did some degree of front-loading of the course, using early class meetings to teach students the basic laboratory techniques and skills that are specific to, and necessary for, the students to complete their research projects.

In both versions of the course, students generally worked collaboratively in pairs, which were formed by student choice and/or by seating arrangement. Most typically students worked with their laboratory benchmate. In both versions of the course, students had the ability to develop their own questions (within boundaries set by the instructors), and in both cases, the research questions and hypotheses were developed after students had begun to read the literature and learn more about the particular system in each course (ant behavior and genetics, and genes that influence eye development in fruit flies and humans, as described below). In the ants course, students had more flexibility to develop wider-ranging questions. In the fly eye course, students developed their research questions and hypotheses based on a collection of genes that had been pre-identified as potentially having a role in eye development. Thus their choice of an individual gene to study was limited, although there were more genes to choose from than there were student groups.

As noted above, the research questions and hypotheses were developed after students started to become familiar with the relevant scientific literature. To provide structured and scaffolded practice reviewing and dissecting the primary literature, both instructors incorporated student presentations of papers from the primary literature and their research proposals (which incorporated the primary literature). In both cases, students received constructive feedback from the instructor, the graduate teaching assistant, and the undergraduate teaching assistant. Each CURE culminated in a student poster session in which students presented their research as a scientific poster, as they would at a scientific conference.

In terms of student projects, one instructor had students work on two successive projects during the semester. The overall theme was the connection between social behavior and genetics, using local harvester ants as a model system. In the first project, students generated their own questions and hypotheses for a field-based study of harvester ant colonies (focusing on social interactions within or between colonies). The students then used molecular genetic tools to test their hypotheses about genetic diversity within colonies or genetic relatedness between colonies. Finally, students tied their two projects together in their poster, linking the genetic results to the social interaction data. In this case, the student projects were completely independent of the faculty member's research program, which uses a vertebrate animal model system that is not amenable for project completion by novice researchers in the compressed time available in a course. However, the instructor's research focus is on genetics and behavior, allowing them to bring their expertise to the students in the course. Thus this course design was a hybrid between the two CURE models discussed above.

The other instructor used a CURE model in which students worked on aspects of the instructor's research program. In this case, the overall goal was to use genetic techniques in the fruit fly to study the functions of genes about which little is known but that have been linked to human eye diseases. Each pair of students chose a gene and designed an experiment to test whether or not that gene played a role in eye development. Each student pair studied what was known about their gene (based on the scientific literature and genetic databases) and generated hypotheses about how that gene could be influencing eye development (based on what was known about the function of the gene). They then developed and defended a proposal of research to be carried out, used molecular biological methods to manipulate the expression of that gene during eye development and verify that the expression had indeed been altered, and observed the impact on the development of eyes. While not all students were able to generate results, they were all able to generate a hypothesis supported by the primary literature, to generate a reasonable experimental design, and to successfully present these during the poster session. Others generated results, carried out quantitative analyses of the data, and presented their results, conclusions, and future direction during the poster session.

Methods and Data Sources

Research Question 1: We have used institutional data to determine demographic characteristics and the one-year post-CURE outcomes with respect to STEM enrollment and STEM graduation. Our participants for the former (demographics) include all CURE participants from completed CUREs (six offerings through spring 2018), and for the latter, the subset of former CURE students who are one year out from their CURE completion.

Research Question 2: We administered a pre- and post-course survey to students in the spring 2018 iteration of the CURE (Table 3). This survey is based on published instruments (Chemers et al., 2011; Estrada et al., 2011) to measure key constructs of scientific self-efficacy, scientific identity, valuing science community objectives, and intention to persist. These are important short and intermediate CURE outcomes that contribute to long-term persistence in STEM (Corwin et al., 2015). Students used a unique identifier (known only to them) on their pre- and postsurveys, allowing responses to be matched by student while preserving student anonymity. As the survey administration was anonymous, it is not possible to link survey gains with institutional data on a per-student basis. However, the survey includes items that allow students to self-report age, gender, race, ethnicity, and academic level (freshman through senior).

Students responded to survey items on a Likert scale (provided for each construct in Table 3). Eleven of 16 registered students completed both the pre- and the postsurvey. We calculated class means for each survey item (pre- and post-) and used a paired, 2-tailed *t*-test to compare the pre- and postsurvey scores for each item. We also report the Cohen's *d* for effect size for each item.

Items (arranged by construct)

Scientific Self-Efficacy
Scale: 1 (not at all confident) to 5 (absolutely confident)

I am able to use technical science skills (tools, instruments, and/or techniques)

I am able to generate a research question to answer

I am able to figure out what data/observations to collect and how to collect them

I am able to create explanations for the results of a study

I am able to use scientific literature and/or reports to guide research

I am able to develop conclusions (integrate and coordinate result from multiple studies)

Scientific Identity
Scale: 1 (strongly disagree) to 5 (strongly agree)

I have a strong sense of belonging to the community of scientists

I derive great personal pleasure from working on a team that is doing important research

I have come to think of myself as a "scientist"

I feel that I belong in the field of science

The daily work of a scientist is appealing to me

Valuing Scientific Community Objectives
Scale: 1 (not like me at all) to 5 (very much like me)

A person who thinks it is valuable to conduct research that builds the world's scientific knowledge

A person who feels discovering something new in the sciences is thrilling

A person who thinks discussing new hypotheses and ideas between scientists is important

A person who thinks that scientific research can solve many of today's world challenges

Intention to Persist
Scale: 1 (definitely will not) to 10 (definitely will)

To what extent do you intend to pursue a science-related research career?

Table 3. CURE survey items, arranged by construct. The response scale for each construct is provided.

Findings

We are reporting on 108 students who have completed our CURE over six semesters (through spring 2018) and four instructors. Academic and demographic characteristics of CURE students are reported in Table 4. The average age of all CURE students is 22.5 years (range 18–42; SD = 4.2). Excluding an influential student (age 42 years) gives an average age of 22.3 years (SD = 3.7).

Characteristic	n	%
Class Standing		
Freshman or Sophomore	20	18.5
Junior	33	30.6
Senior	55	50.9
Gender		
Female	70	64.8
Male	38	35.2
Race/Ethnicity		
URM*	76	70.3
Hispanic	65	60.2

**Includes Hispanic (86% of the URM population in this study), as well as American Indian/Alaska Native, Hawaiian/Pacific Islander, and Black (each of which includes less than seven students, preventing individual reporting, per institutional policy).*

Table 4. Academic and demographic characteristics of the 108 CURE students over six semesters of the CURE.

Persistence in STEM

Persistence in STEM has been defined as students remaining in a STEM track one year after their CURE completion (Corwin et al., 2015; Jordan et al., 2014). We have examined the one-year post-CURE status for the 92 students who are at least one year out from completing the CURE, recording outcomes that indicate persistence in STEM. Almost 86% of all students, close to 80% of URM students, and approximately 85% of female students have either graduated with a STEM degree, remain enrolled in a STEM major, or are newly enrolled in a STEM major (i.e., have switched to a STEM major from a non-STEM major) (Table 5). Note that students who are newly enrolled in a STEM major represent only 5.4% of the 92 students who are one year out from CURE completion.

Psychological Predictors of Persistence

Eleven of 16 students completed the pre- and postcourse surveys in spring 2018. Based on self-reported data, the 11 students who completed both the pre- and postsurveys were predominately female (81.8%). Over 80% of the 11 participating students identified as Hispanic, and all were biology majors. Ten of the 11 participating students were seniors, and the average age of the 11 participating students was 24.8 years (SD = 3.7).

The survey results (Table 6) showed statistically significant shifts toward "more confident" on all six items of the Scientific Self-Efficacy scale, with five having a large effect size. All five items on the Scientific Identity scale showed a positive shift, two of which were statistically significant. Both of the significant items had a large effect size (> 0.8). One of the four items on the Scientific Community Values scale showed a significant shift (with a large effect size), although all items showed a positive shift toward "very much like me." There was a statistically significant and positive shift on the single item of the Intention to Persist scale, with a large effect size of 0.91.

Outcome	Number	% (of 92 students)	Number URM	% (of 61 URM students)	Number Female	% (of 59 female students)
Degree completed in a STEM major	29	31.5	17	27.9	15	25.4
Still enrolled in a STEM major	50	54.3	31	50.8	35	59.3

Table 5. One-year post-CURE outcomes that indicate persistence in STEM.

Discussion

Our CURE is clearly serving a diverse population of students (Table 4). At 64.8% female and 60.2% Hispanic, our CURE participants include a higher proportion of females and Hispanics than our institution as a whole (between 53.9% and 54.9% female and between 49.7% and 54.4% Hispanic in the same interval; Office of Institutional Analysis, New Mexico State University). The demographics of our CURE students closely match those of the Biology Department (56.3%– 62.8% Hispanic and 66.4%–68.7% female). This suggests that our CURE fosters broad participation, consistent with a research experience via course enrollment rather than by a selective application process (Bangera & Brownell, 2014; Elgin et al., 2016). By providing a diverse group of students with an authentic research experience, we are contributing to an inclusive research environment, and possibly stimulating student interest in continuing participation in research.

As noted above, our CURE objectives align with national objectives (PCAST, 2012) in that we want to provide an early-stage authentic research experience for STEM-interested students. We have been surprised at the high proportion of advanced students enrolling in our CURE, which was primarily, although not exclusively, targeted toward and marketed to early career students (Table 4). This trend suggests that our CURE is filling a gap for more senior students who have previously not had a research experience, either because of interest arising later in their academic career, and/or because of limited departmental capacity to provide mentored research apprenticeships to all interested students, a recognized barrier to participation in research (Auchincloss et al., 2014; Bangera & Brownell, 2014; Elgin et al., 2016). As noted above, although we are enrolling a high proportion of more advanced students, the course is not yet reaching capacity. On average, there are ~7 seats remaining open each semester (range 3–10), suggesting that we have not excluded

Survey Items	Pre	Pre SD	Post	Post SD	*p*	T	Cohen's *d*
Scientific Self-Efficacy (1–5 scale)							
Technical skills	3.91	0.70	4.45	0.52	0.03	2.63	0.79
Research questions	3.36	0.92	4.45	0.52	0.01	3.46	1.04
Data collection	3.18	0.98	4.27	0.90	0.01	3.18	0.96
Explanations	3.55	1.04	4.36	0.67	0.01	3.11	0.94
Sci. literature	3.27	1.19	4.18	0.75	0.02	2.89	0.87
Conclusions	3.36	1.29	4.36	0.81	0.02	2.80	0.85
Scientific Identity (1–5 scale)							
Belong to community	3.82	0.87	4.64	0.67	0.01	3.11	0.94
Pleasure in teamwork	3.82	0.98	4.27	1.10	0.18	1.46	0.44
Am a scientist	3.64	1.12	4.55	0.52	0.01	3.19	0.96
Belong in science	4.18	1.25	4.73	0.65	0.14	1.60	0.48
Sci. work is appealing	3.73	1.19	4.27	0.90	0.11	1.75	0.53
Scientific Community Values (1–5 scale)							
Research is valuable	3.73	1.01	4.18	0.87	0.02	2.89	0.87
Discovery is thrilling	4.36	0.92	4.45	0.93	0.76	0.32	0.10
Discussing with scientists is important	3.55	0.93	4.00	1.26	0.14	1.61	0.49
Research can solve world problems	4.55	0.69	4.64	0.67	0.76	0.32	0.10
Intention (1–10 scale)							
Pursue science career	6.55	2.98	7.91	2.77	0.01	3.01	0.91

**The degrees of freedom for all items is 10.*

Table 6. Pre- and postsurvey means, standard deviations, p-values, T statistics, and Cohen's *d* from paired two-tailed T-tests.* Items are grouped by construct.

beginning students from enrolling. Thus, any skew toward more advanced students appears to reflect demand, rather than exclusion of less advanced students.

Our one-year post-CURE outcomes are positive with respect to measures of persistence (Table 5). Our relatively high STEM graduation rates in the year since CURE completion (31.5% for all students and 27.9% for URM students) likely reflects the high proportion of seniors (50.9%) in our CURE. Our high persistence rates (54.3% of all students and 50.8% of URM students enrolled in a STEM degree program one year post-CURE completion) may also be influenced by the high proportion of juniors and seniors. Rodenbusch et al. (2016) reported higher STEM graduation rates for students participating in a three-semester CURE (starting in their first semester) than for students who did not participate in a CURE. Similarly, Jordan et al. (2014) reported a first- to second-year retention rate of approximately 93% for students who completed the year-long SEA-PHAGES CURE in their first year. Our combined one-year post-CURE graduation and persistence rates are similarly quite high—85.8% for all students and 78.7% for URM students (Table 5). However, this positive result may be biased by the more advanced students in our CURE. The highest attrition from STEM typically occurs earlier in the academic pathway (e.g., PCAST, 2012), so we cannot definitively state that our CURE is transformative for early-stage students. As we eventually have more students at all levels participate in our CURE, we would like to specifically compare outcomes for freshmen/sophomores and juniors/seniors.

Despite the potential bias in one-year measures of persistence presented by advanced students enrolling in our CURE, we are still seeing significant gains in psychological indicators of persistence, suggesting that even advanced students can still gain in critical areas (90.9% of students completing the surveys were seniors) (Table 6). For example, there were significant gains in all items of the Scientific Self-Efficacy scale, suggesting that even advanced students have room to enhance their self-efficacy. Furthermore, there were positive shifts on all items of the Scientific Identity scale, including two significant shifts with a large effect size ("I am a scientist"; "I belong to the community"). This is in contrast to observations in an upper division and advanced biochemistry CURE (Shanle, Tsun, & Strahl, 2016) in which there were no detectable shifts in scientific identity over the course of the CURE. However, their measure of scientific identity had two items ("I am a researcher" and "I am a scientist") that may not have been able to address this construct at a finer grain. It is interesting that we saw significant gains on a Scientific Identity scale item ("I am a scientist"), which was not observed by Shanle, Tsun, and Strahl in an upper division biochemistry CURE (2016). This is an example that supports the argument for the field using common and validated instruments, so that results of different studies can be more meaningfully compared and differences can be more readily attributed to differences in the CURE or students, rather than the assessment instruments used. In our CURE, most of the nonsignificant gains were in the area of scientific community values. However, for many of the items with nonsignificant gains, precourse means were already high, leaving relatively little room for improvement (potentially reflecting advanced status and already developed appreciation for science) (e.g., items including "belong in science," "discovery is thrilling," "research can solve real-world problems").

The fact that we are seeing significant gains in scientific self-efficacy and scientific identity is important, as they can be predictors of persistence in STEM (Corwin et al., 2015; Estrada et al., 2011; Hernandez, Wesley Schultz, Estrada, Woodcock, & Chance, 2013). The observed gains in these areas, as well as the significant gain on the intention to persist item on our survey ("To what extent to do you intend to pursue a science-related research career?") (from 6.55 precourse to 7.91 postcourse) (Table 6), appear to be borne out by our actual measures of one-year post-CURE persistence (Table 5).

Limitations

As discussed above, while we intended to enroll students who had recently completed their introductory biology courses, the highest demand was from more advanced students. While this opens questions about why the course was so attractive to more advanced students, it also may influence the survey results, as one might expect more advanced students to have high senses of scientific self-efficacy, scientific identity, and scientific community values. We did observe relatively high presurvey scores, but were surprised to see significant shifts, particularly on items related to scientific self-efficacy and scientific identity. Until we have more lower division students participate, we will not be able to determine the impact of our CURE on the intended target population.

As this study was intended to determine "what is" happening with respect to important predictors of persistence (Bass, 1999), we focused on collecting data that would allow us to measure these indicators. However, we are unable to determine why these shifts are occurring, particularly in our sample with a high representation of academically advanced and traditionally underrepresented students. Qualitative data in the form of surveys or focus groups would allow us to begin to understand what might be driving the observed shifts and to make design tweaks to the course to foster such shifts.

Future Directions

As we continue to offer our CURE, we will continue to use assessment and evaluation to better understand the impact of our CURE on measures and predictors of persistence for freshmen and sophomores. These data will allow us to address several outstanding questions regarding CUREs. For example, can our CURE impact psychological predictors of persistence in freshmen and sophomores to the same extent that we observe for our seniors? Can participation in our CURE influence persistence for both URM and non-URM freshmen and sophomores (relative to students who do not participate)? We are also interested in continuing to evaluate the impact of the CURE on our more advanced students. While there were positive shifts on survey items predicting persistence, the precourse means were relatively high. Does this mean that our CURE is primarily confirmatory (e.g., Lopatto, 2007; Seymour, Hunter, Laursen, & Deantoni, 2004; Thiry, Laursen, & Hunter, 2011) with respect to STEM persistence for these more advanced students, or is it having a transformative impact (e.g., Villarejo et al., 2008)? Finally, as is the case for the field in general, we would also like to better understand what aspects of our CURE are contributing to our measures and predictors of persistence, so we can ensure these aspects are maintained across all iterations of our CURE (Auchincloss et al., 2014; Corwin et al., 2015; Shortlidge & Brownell, 2016). For example, a recent study found that project ownership mediated the positive impacts of CURE design elements of discovery, iteration, and collaboration on scientific career intentions (Corwin et al., 2018). Will this be true in a CURE at a minority-serving institution with a high URM population?

Finally, while not a focus of this study, we have worked to adapt an ant behavior research question from one CURE iteration for an introductory biology inquiry lab, and it is our intention to continue to use CURE research questions and findings as the basis for classroom PBL or CBL activities. This effort enacts the suggestions of Pierrakos, Zilberberg, and Anderson (2010), whose work suggests that research questions have the potential to be effective classroom PBL problems.

In conclusion, we have developed a CURE that serves a large proportion of students who are underrepresented in STEM. We have found that students show positive shifts on psychological indicators of persistence and have high rates of STEM persistence one year after completion of the CURE.

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