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Research Article

A CURE lab in an introductory biology course has minimal impact on student outcomes, self-confidence, and preferences compared to a traditional lab

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ABSTRACT Course-based undergraduate research experiences (CUREs) have grown in popularity, particularly within introductory biology courses, to provide more students with authentic research experiences. CUREs have been shown to have many of the same positive effects as conventional research experiences; however, most assessments of CUREs lack an appropriate comparison group to evaluate their effectiveness. Here, we introduced a CURE into an introductory biology lab at a regional public university but maintained a traditional, "cookie-cutter" lab in half the lab sections over a 3-year period. We compared changes in test scores and survey responses, final lab and lecture scores, and D, F, withdrawal, and incomplete (DFWI) and retention rates between non-honors biology students in each group. While both groups showed significant improvement in test scores, only transfer students had significantly greater improvement in the CURE vs traditional lab. Students in both groups showed significant increases in self-confidence in some lab-related tasks, but differences in these changes were generally not significant between groups. There were no significant differences in final lecture score, lab score, DFWI rate, or retention rate. Factors affecting the lack of measured CURE success may include the type of CURE chosen, student career interests, and COVID-19; other positive impacts of the CURE may not have been captured by our measurements. This study demonstrates the importance of carefully choosing a CURE to match the student population, as well as assessing the CURE's impact against a comparison group.

KEYWORDS antibiotic resistance, authentic research experience, CURE assessment, microbiology, pedagogy, retention, transfer student

Recent efforts to reform undergraduate STEM education and increase retention have included calls to provide a research experience for all students, identified as a high-impact educational practice (1–3). Benefits of student research include increased content knowledge, technical and analytical skills, and self-efficacy (4); increased retention and graduation rates in STEM fields (3, 5–7); and increased interest in pursuing science and science-related fields after graduation (2, 8). These benefits may be even more pronounced for traditionally underrepresented students in STEM (9–11). However, because student research experiences are conventionally accomplished through research internships or independent studies, they are typically only available to small numbers of upper-level students. This limited availability often makes them inaccessible to traditionally underrepresented students and can perpetuate the achievement gap (9). Moreover, their effect on retention is lessened compared to early research experiences (12). Making more opportunities available to students during their first 2 years of undergraduate education may provide the full benefits of student research (13).

Course-based undergraduate research experiences (CUREs) have emerged as a solution to this problem. Unlike traditional labs with experiments that have known

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outcomes for instructors, CUREs incorporate novel research into the lab that contributes to the broader scientific community (14, 15). CUREs are typically differentiated from other learning experiences by including five components: engagement in the process of science; discovery of novel findings; relevance to the broader scientific community; collaboration with other students; and iteration within or across semesters (14). CUREs have been shown to provide many of the same benefits as conventional research but are more accessible to students earlier in their careers (4, 16, 17). Additionally, because everyone enrolled in a course partakes in the research, CUREs overcome some of the barriers that prevent students, particularly those from traditionally underrepresented groups, from gaining research experience (9). Some of these barriers may cause students to leave STEM programs before they take upper-level CURE courses (9). Therefore, it is recommended that CUREs be implemented into introductory courses to maximize the benefits of research, particularly those related to retention (9). However, implementing a CURE into a large-enrollment, introductory-level course can be challenging, particularly for non-research-oriented institutions (18). Some obstacles to implementing a CURE include the logistics of scaling research projects to an entire lab section, completing research studies within a semester, monetary cost to conduct research, and resistance from students, other faculty, and administration (19, 20).

Despite an extensive literature on CURE effectiveness, most studies on CURE learning outcomes, for logistical reasons, cannot use a randomized controlled study to compare students who are and are not taking a CURE lab (19, 21). Here, we introduced a CURE into the lab curriculum of the introductory biology course for majors at a moderately sized regional public primarily undergraduate institution in the northeastern United States. To evaluate the effectiveness of this approach, we introduced the CURE into some lab sections while maintaining the traditional approach in other lab sections of the same course. Our research questions were

1. Does the CURE approach improve students' understanding of the scientific method compared to the traditional approach?
2. Does the CURE approach affect students' self-confidence in their scientific abilities, interest in pursuing a scientific career, and preferences toward lab courses compared to the traditional approach?
3. Does the CURE approach increase retention in the Biology program compared to the traditional approach?

We hypothesized that the CURE approach would increase both student comprehension of biological concepts and self-confidence in students' scientific ability to a larger extent than the traditional approach. We hypothesized that students experiencing the CURE approach would be more likely to pursue a scientific career and would have a greater preference for lab courses that are more authentic. Finally, we hypothesized that the retention rate in the Biology program would be higher among students completing the CURE approach.

METHODS

Participants and lab sections

Participants were undergraduate students taking the introductory course for majors, Principles of Biology (hereafter, "Principles"), from Fall 2021 to Spring 2024 (six semesters). Principles is a relatively large-enrollment course (approximately 225–250 students enrolled in fall semesters and 75–100 in spring semesters) that serves as the foundational course for students entering the Biology program. The rate of D, F, withdrawal, and incomplete (DFWI) grades in this course is high (approximately 40%–45% over the 5 years prior to this study, regardless of instructor), contributing to a large number of students leaving the Biology program.

Principles labs have a maximum of 24 students, and all are taught by faculty. Both versions of the lab were taught every semester; individual faculty members chose which version they taught. When multiple lecture sections were taught in a semester, CURE labs were distributed between them. Approximately half (21) of 39 lab sections implemented the CURE during the study period, including three sections for honors students; the remaining 18 lab sections continued to use a traditional approach and served as the control. Students who volunteer for a research-based course may be more predisposed to this type of course design than students who do not volunteer, potentially biasing comparisons (14, 22). To control for this, students were not told which version they were enrolled in until the first day of class.

All students enrolled in the course were invited to participate in the study, regardless of major. This included Biology majors in the four tracks of the Biology program (Pre-Medicine, Allied Health, Organismal/Ecology, and Cellular/Molecular Biology), the Environmental Science–Biology program, and the Marine Science–Biology program (71%); other STEM majors, including Chemistry, Physics, Mathematics, and Computer Science (24%); and non-STEM or undeclared majors (5%). Demographic information of study participants (82% of total students) is shown in Table 1. We included all participants initially but focused our evaluation of CURE effectiveness specifically on non-honors Biology majors. This resulted in a total of 223 participants in traditional labs and 227 participants in CURE labs (23). All students who participated in the study provided informed consent.

TABLE 1 Demographic characteristics of participants in the traditional and CURE groups[a]

Variable	Traditional	CURE
Gender		
Man	120	143
Woman	174	206
Non-binary	6	11
Prefer not to say	3	8
Other	0	1
Race/ethnicity		
Native American/Alaska Native	5	4
Asian	12	10
Black/African American	43	47
Native Hawaiian/other Pacific Islander	1	2
Hispanic/Latino	42	41
White	220	286
Other	2	2
Class year		
Freshman	222	237
Sophomore	44	79
Junior	25	36
Senior	6	13
Post-bacc/other	5	2
First-semester transfer		
Yes	42	51
No	259	319
Major		
Biology	223	247
Other STEM	59	108
Non-STEM	13	11
Undeclared/undecided	6	3

[a]*n* Traditional = 319; *n* CURE = 383. Not all participants answered each question, and some participants chose multiple race/ethnicity categories.

Description of lab approaches

Traditional approach

The traditional approach in Principles lab includes numerous “cookie-cutter” labs that introduce students to various biological concepts and skills, including osmosis, enzyme activity, fermentation, natural selection, mitosis, and DNA technology (Appendix S1). Students also design a research project using *Tetrahymena* as a model organism, where they test whether a chosen treatment affects food vacuole production. This experiment is repeated each semester such that the instructor knows the expected outcomes of any treatment, and there is no external interest in the results.

CURE approach

The CURE introduced into Principles lab was centered on isolating and identifying antibiotic-producing bacteria in soil around Kutztown. The overuse of antibiotics in human health and agriculture has contributed to the rise of antibiotic-resistant bacteria (24). People infected with these bacteria cannot be treated with traditional antibiotics; this has led to an estimated 700,000 deaths worldwide per year, which is expected to increase as antibiotic-resistant bacteria spread (24). Therefore, the discovery of new antibiotics is of utmost importance (25). To implement this CURE, we joined the Small World Initiative, a program designed to crowdsource antibiotic discovery among institutions while simultaneously increasing student persistence and engagement in biology (26). This program provides a suggested procedure for introducing topics and methods to students, though modifications were made to fit the structure of our course and the needs of our students. We also included a smaller number of traditional labs to ensure students received certain skills for later courses (Appendix S1). Safety precautions adhered to ASM guidelines for biosafety in teaching laboratories (27).

Data collection and analysis

To measure changes in how students understand scientific content, participants were given a pre-test during the first lab to collect baseline data. This test included 10 multiple-choice questions covering a range of topics on the scientific method, including generating hypotheses, categorizing variables, proper experimental design, data measurement and interpretation, and displaying results (Appendix S2). These questions intentionally focused on topics covered in both versions of lab, and pre-test scores were not significantly different between groups. Students took a post-test composed of similar questions during the last lab to measure gains in their comprehension. Individual students were randomly given one of two variants of the test at the beginning of the semester and the other variant at the end of the semester (28). We tested for improvement in test scores from the beginning to the end within each group using a paired-samples *t*-test and compared the mean change in each group using an independent samples *t*-test. We performed a five-way repeated measures ANOVA within each group to identify whether demographic covariates (gender, race, class year, transfer status, and prior research) influenced test scores and a six-way between-subjects ANOVA (now including lab version) for the between-group comparison. Only students who completed both pre- and post-tests were analyzed.

To measure changes in factors not related to academic performance, participants were also given a survey at the beginning and end of the semester (Table 2); pre-course survey responses were not significantly different between groups. This survey included three blocks of Likert-type scale questions addressing students’ self-confidence in their abilities to perform specific research tasks, level of interest in pursuing future research-related experiences, and preferences for lab courses (29). Responses were scaled to numerical representation for statistical analysis. We tested for changes in survey responses within each group using a paired-samples *t*-test and compared the mean change in each group using an independent samples *t*-test. We performed a five-way repeated measures MANOVA to identify whether any demographic covariates

TABLE 2 Mean change (standard error in parentheses) in response from pre-course to post-course survey for both groups (traditional vs CURE) on three sets of questions (29)[a,b]

Survey question	Mean change (standard error)		*P*-value
	Traditional	CURE	
How confident do you feel in your ability to execute the following biology lab-based tasks?			
Develop my own scientific question.	0.880 (0.091)**	0.614 (0.079)**	0.036
Design my own experimental lab protocol.	0.982 (0.083)**	0.702 (0.092)**	0.032
Interpret experimental data.	0.630 (0.086)**	0.558 (0.078)**	0.487
Present lab results to my lab partners.	0.542 (0.084)**	0.542 (0.092)**	1.000
Write an accurate full-length lab report (Intro, Methods, Results, Discussion)	0.873 (0.092)**	0.536 (0.114)**	0.014
Work as an undergraduate research assistant in a biology lab.	0.602 (0.095)**	0.328 (0.107)	0.067
What is your level of interest for doing the following research-related experiences?			
Applying for biology or other science-related undergraduate lab research positions.	0.006 (0.109)	−0.079 (0.116)	0.594
Doing biological research after graduation.	−0.105 (0.094)	−0.458 (0.099)**	0.016
Doing non-biological scientific research after graduation.	0.172 (0.100)	0.115 (0.103)	0.586
What is your level of agreement with the following statements related to biology lab courses?			
I prefer lab courses that explore a set of research questions focused on a single continuous topic for the semester.	−0.189 (0.085)	−0.250 (0.102)	0.647
I prefer to make my own decisions about what experiments to do in lab courses.	0.019 (0.078)	0.006 (0.074)	0.906
I prefer lab courses that explore an open-ended question for which the answer is not predetermined.	0.018 (0.079)	−0.109 (0.092)	0.293
I believe that collaboration is an important part of lab courses.	−0.080 (0.084)	−0.046 (0.084)	0.674

[a] *n* Traditional = 166; *n* CURE = 166. Question 1 scale = (1) not confident, (2) somewhat confident, (3) moderately confident, (4) very confident, and (5) extremely confident. Question 2 scale = (1) not interested, (2) somewhat interested, (3) moderately interested, (4) very interested, and (5) extremely interested. Question 3 scale = (1) strongly disagree, (2) disagree, (3) do not agree or disagree, (4) agree, and (5) strongly agree. A significant difference ($\alpha = 0.003$) between the pre-course and post-course survey within a group is indicated by an asterisk: *$P < 0.003$ and **$P < 0.001$.
[b] The *P*-value represents the statistical difference in mean change in response between the two groups using an independent-samples *t*-test.

corresponded to changes in survey response within each group across all survey questions and a six-way between-subjects MANOVA (now including lab version) for the between-group comparison. To maintain a desired α level of 0.05 for each of the 17 survey questions, we applied a Bonferroni correction of $\alpha = 0.003$. Only students who completed both pre- and post-course surveys were analyzed.

We compared final lab and lecture scores among all students receiving a letter grade using an independent samples *t*-test and six-way between-subjects ANOVA to determine whether the CURE impacted overall course success. We calculated the DFWI rate for each semester and year-to-year retention in the biology program among all students in the study at the start of each academic year following the implementation of the CURE, using a χ^2 test of independence to identify differences between groups. All analyses were performed using IBM SPSS Statistics (version 28.0.1.0).

RESULTS

Students in the CURE lab ($t[159] = -7.601$, $P < 0.001$) and the traditional lab ($t[147] = -6.609$, $P < 0.001$) scored significantly higher on the post-test compared to pre-test by an average of approximately 12 percentage points, from 45% to 57% (Fig. 1). This difference in improvement was not significant between groups, $t(306) = 0.341$, $P = 0.733$ (Fig. 1). The five-way repeated measures ANOVA and the six-way between-subjects ANOVA revealed a significant interaction effect with several demographic covariates on test performance in both the CURE and traditional labs, as well as the difference between them (Appendix S3). Interaction plots between these variables revealed that in the traditional lab, students without prior research experience improved their test scores significantly more than students with prior research experience; in the CURE lab, students identifying as men improved their test scores significantly more than students identifying as women or non-binary; and transfer students improved their test scores significantly more in the CURE lab than in the traditional lab.

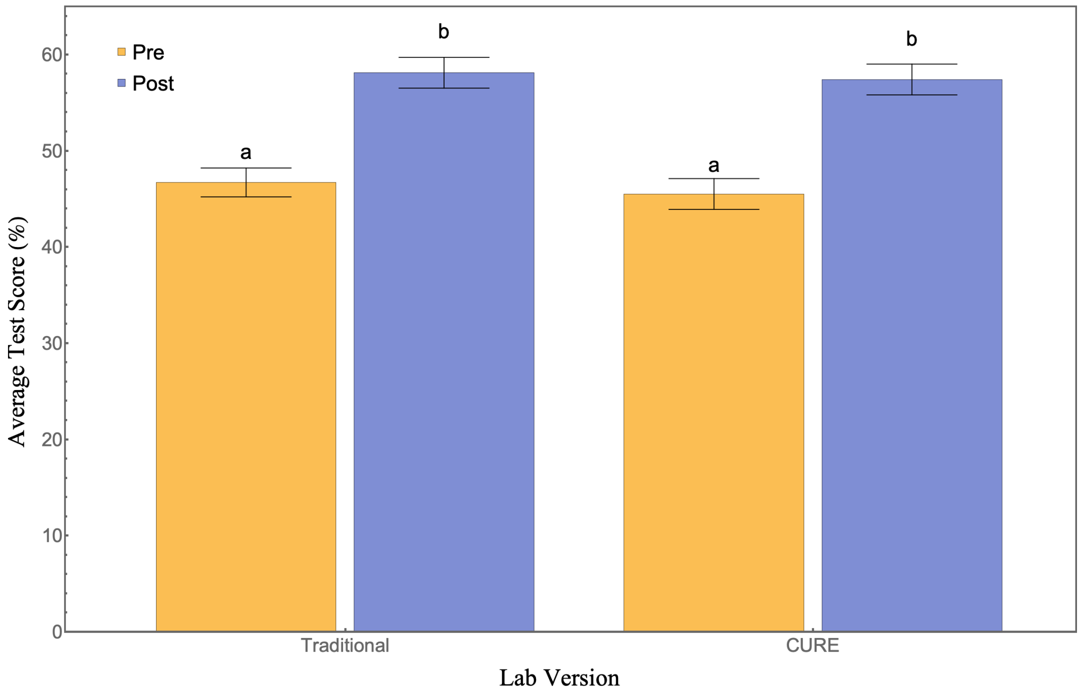

FIG 1 Average test score (percentage of 10 points) on the pre- and post-test for students enrolled in the traditional and CURE versions of the lab. Error bars represent standard error. Different letters signify a significant difference between the pre- and post-test. There was no significant difference in the change in test scores between the different versions of the lab ($P = 0.733$).

Students in the CURE lab showed significant gains ($\alpha = 0.003$) in five of six questions related to self-confidence in lab-based abilities, including developing a scientific question (+0.614), designing a lab protocol (+0.702), interpreting experimental data (+0.558), presenting lab results to lab partners (+0.542), and writing a full-length lab report (+0.536, Table 2). Students in the traditional lab showed significant gains in all six questions, including working as a research assistant; most of the gains were larger than the CURE lab, but not significantly ($\alpha = 0.003$; Table 2).

Students in the CURE lab had significantly decreased interest in doing biological research after graduation (−0.458, Table 2). Neither of the other questions related to interest in pursuing research-related experience was significant, nor were any of the changes among students in the traditional lab or between groups ($\alpha = 0.003$; Table 2). There were no significant changes in response to questions focused on students' preferences for the type of lab course in either the CURE or traditional lab nor were any of the changes significantly different between groups ($\alpha = 0.003$; Table 2).

The five-way repeated measures MANOVA and the six-way between-subjects MANOVA revealed significant interaction effects with several demographic covariates on some survey questions (Appendix S4). Interaction plots between these variables revealed that in the traditional lab, Native American and Native Hawaiian students had a significant increase in preference for lab courses that explore open-ended questions (Q3c), and students identifying as non-binary had a significant increase in the belief that collaboration is an important part of lab courses (Q3d). There were no significant interaction terms in the CURE lab, while Freshman students in the traditional lab had a significantly larger increase in confidence in working as an undergraduate research assistant (Q1f) than in the CURE lab.

Neither average final lab grades ($t[402] = -1.923$, $P = 0.055$) nor average final lecture grades ($t[402] = -0.364$, $P = 0.716$) were significantly different between groups (Fig. 2), even when excluding grades of D and F. The six-way between-subjects ANOVA revealed no significant interaction terms with lab version (Appendix S5). While the average final lecture grades were nearly identical between groups, there was a nearly significant difference in final lab grade: 70.41% for traditional vs 65.74% for CURE (Fig. 2). This is likely due to differences in assessment tools between the versions of lab; groups covered different materials, so they had different quizzes, papers, and other activities, making direct comparison difficult (Appendix S1).

There was no significant difference in DFWI rate between CURE and traditional labs, χ^2 (1, N = 445) = 2.206, P = 0.137 (Fig. 3). The higher DFWI rate in the CURE is primarily driven by a large (though not significant) difference during the first semester the CURE was taught (40.13% for traditional vs 45.45% for CURE, Fig. 3); subsequent semesters had very similar DFWI rates between lab versions.

There was no significant difference between students in CURE and traditional labs in retention to year 2, χ^2 (1, N = 431) = 0.723, P = 0.395; year 3, χ^2 (1, N = 189) = 0.711, P = 0.399; or year 4, χ^2 (1, N = 76) = 1.178, P = 0.278 (Fig. 3). However, retention was on average 5 percentage points higher in CURE labs than traditional labs across all years (Fig. 3); this was primarily driven by the first cohort of students, which had a nearly 10 percentage point difference in retention between lab versions.

DISCUSSION

In this controlled study, we show that while CUREs can be effective at increasing students' content knowledge and self-confidence in scientific abilities, this is not always different from what a traditional lab approach can accomplish. Despite the lack of a larger improvement in test scores among CURE students, it is notable that there was no reduction in gains of content knowledge compared to traditional students despite CURE students having less time in the lab for repeated coverage of fundamental laboratory skills and reinforcement of lecture topics. Reduction in content knowledge gains is a concern and can occur when implementing a CURE into an introductory course (30). One of the features of traditional labs is their formulaic approach, which allows students to experience numerous different lab experiments that help build their skills, possibly to a greater extent than CURE labs, which tend to be more focused in nature. By presenting

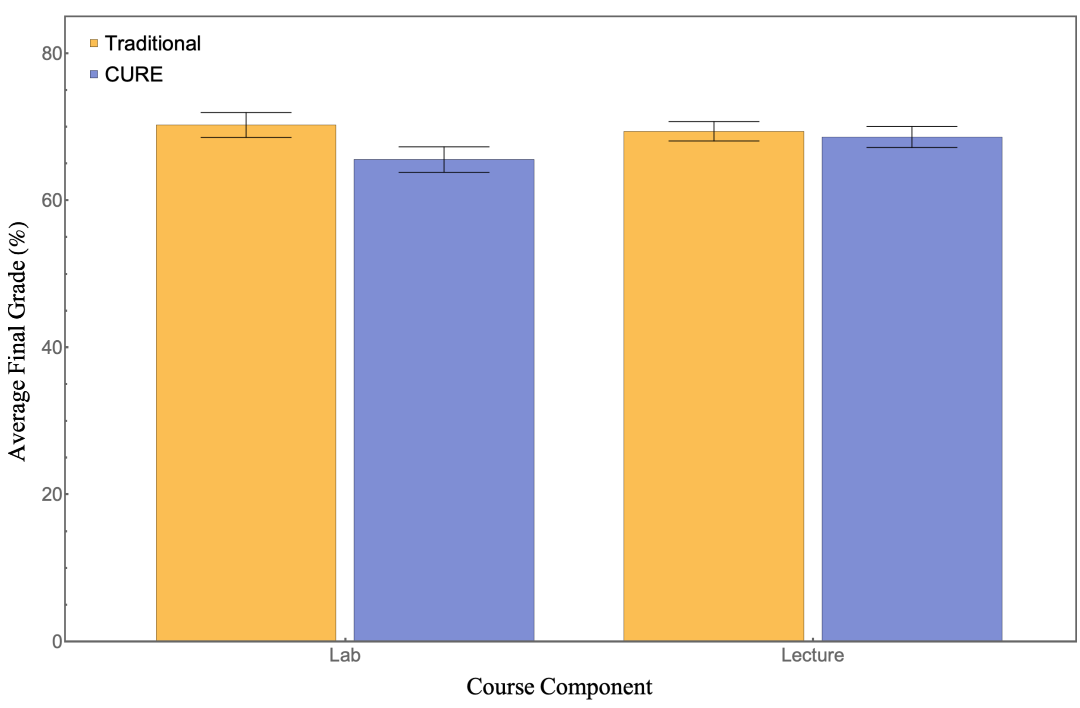

FIG 2 Average final grade (percentage) for the lab and lecture components of the course for students enrolled in the traditional and CURE labs. Error bars represent standard error. There was no significant difference in final lab grade (P = 0.055) or final lecture grade (P = 0.716) between the different versions of the lab.

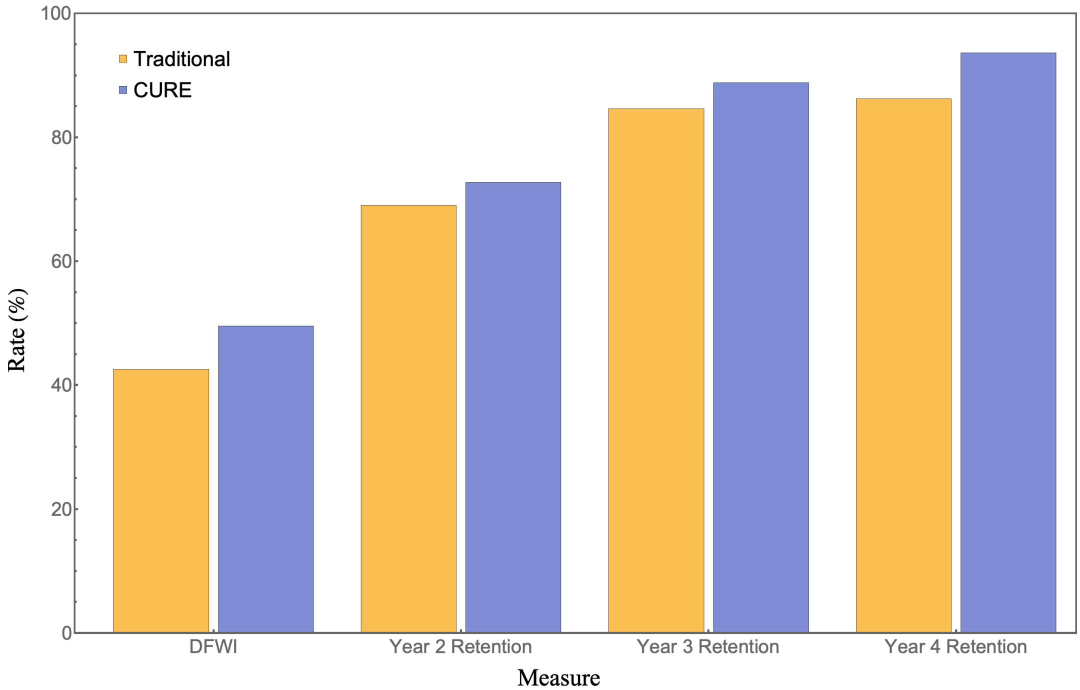

FIG 3 Rate of DFWI grades and year-to-year retention in the Biology program for years 2, 3, and 4 following enrollment in the Principles of Biology course. There was no significant difference in DFWI rate between the different versions of the lab ($P = 0.137$) or for year 2 ($P = 0.395$), year 3 ($P = 0.399$), and year 4 ($P = 0.278$) following completion of the Principles lab.

CURE students with more authentic lab opportunities, we may have also exposed them to more difficult approaches that corrected misconceptions about their own readiness, leading to smaller gains in self-reported confidence for lab-related tasks than traditional students. This may ultimately be a benefit to CURE students; however, as research has shown, overconfidence in abilities corresponds with lower persistence and poor learning strategies, particularly among STEM students (31).

Our study began during the COVID-19 pandemic as students returned to the classroom full-time. The effects of the pandemic on undergraduate students have been well documented, including stress and anxiety, lack of preparedness and motivation, and mental and emotional health issues (32, 33), which likely affected student performance equally between groups. Traditional students in the first cohort of the study were less likely to be retained than CURE students, indicating a possible mitigating effect of the CURE during the later stages of the pandemic; for subsequent cohorts, traditional student retention increased to be similar to that of CURE students. The significant decrease among CURE students in their desire to conduct biological research after graduation, along with the lack of a significant increase in retention compared to traditional students, may be attributable to the effect of students receiving "real-world experience" in their intended career path and deciding that they do not want to continue (34). While not an intended effect of the CURE, we would argue this is a beneficial outcome for students, if not the program, as it saves them from pursuing a career in something they may ultimately not enjoy. Additionally, approximately 60% of incoming Biology majors were in the Pre-Medicine and Allied Health tracks; these students may not see themselves as researchers or have any interest in pursuing research-oriented careers. Their potential lack of interest in research may have decreased the impact of the CURE (35).

The specific CURE chosen may have also played a role in the lack of effect. Although the search for novel antibiotics has impactful real-world ramifications, in practice, few students isolated bacteria with antibiotic activity. This was expected and communicated with students in advance; however, scientific setbacks can be difficult to process, particularly for mostly first-year students without prior research experience (36). While negative results are certainly common in science, a different research experience with a higher success rate may have been more effective. For example, the Science Education Alliance-Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) program has students investigate viral diversity and evolution, providing them with a high probability of isolating a bacteriophage with a new genome or unidentified genes (37). For the most part, we also failed to observe a positive impact of the CURE on students from traditionally underrepresented backgrounds in STEM, suggesting that these factors may have impacted students of all demographic groups equally. The significantly greater improvement in test scores among CURE transfer students is encouraging, as this demographic often faces challenges associated with attending a new institution (38, 39). We do not believe there was an effect of instructor on the results; since the faculty chose whether to teach the CURE, we would expect more positive outcomes than if they were assigned a CURE (40).

As the scientific literature on the implementation and effectiveness of CUREs grows, it is important to continue to assess this teaching practice using the same scientific rigor we expect our students to use within the CURE (22). Despite Brownell and colleagues' (22) call over 10 years ago to be mindful of factors, such as proper controls, student self-selection bias, student achievement level, and small sample size, we found few published studies that address or account for them (30, 41–46). Of those that compared changes in content knowledge, Olimpo et al. (42) found no significant differences in midterm or final exam grades between groups, and Casper and Laporte (30) found a decrease in lecture exam scores among BIPOC and Pell-eligible CURE students; Jordan et al. (41) found significantly higher lecture grades among CURE students, but students were not randomly assigned for this CURE, allowing for potential self-selection bias (41). Other studies used pre- and post-course surveys or tests to compare changes in student self-confidence (44, 46), attitudes and motivation in biology (42, 44, 46), experimental design ability (43, 46), and ownership and perception of relevance (30, 45). All found a positive effect of the CURE on measured outcomes compared to the comparison group (30, 42–46), though two may have been affected by student self-selection bias (30, 44); Casper and Laporte (30) actually tested for selection bias and found that non-volunteer students had smaller gains than volunteer students. Only Jordan et al. (41) compared retention between students taking a CURE lab and other STEM majors, finding higher retention among CURE students. Indorf et al. (44) found that the time to graduation was significantly reduced for students taking the CURE version of the lab compared to the traditional version. Notably, students were not randomly assigned a lab version in either of these studies (41, 44).

Our results reveal a few key points that are often not measurable in CURE research. First, in many situations, the traditional lab approach can be effective at helping students meet learning objectives and preparing them for a scientific career. Second, it is important to carefully consider the student population when deciding whether to implement a CURE and which specific CURE would be effective at meeting intended outcomes. For introductory students who may not have much lab-based learning experiences or may be lacking in preparation and study skills, a CURE with a low success rate may not have the expected positive impact. Third, the CURE approach may have benefits that could not be measured by our assessment. Our learning assessment by design focused on general lab concepts and techniques covered by both lab versions rather than topics specific to our CURE research. Learning more about a specific domain of science is valuable and may render a CURE approach useful even if it has no effect on general laboratory and scientific skills. Other unmeasured effects may include positive faculty experiences teaching a CURE (47) and students' sense of ownership over the project (30), which was not assessed by our survey. Finally, the benefits of CURE participation may not be apparent until many years afterward (48). Continued tracking of retention and graduation rates, and follow-up surveys, might reveal longer-term effects of CURE participation (7, 48).

Our study demonstrates the importance of using a comparison group to evaluate the impact of introducing a CURE lab into an introductory biology course. Our results are limited to a single regional university that serves primarily undergraduate students; nevertheless, they may be widely applicable given the relative lack of comparison studies in the literature and inconsistent results among published comparison studies. We recommend that instructors introducing a CURE include a comparison group when possible and evaluate both the short-term and long-term effects of the CURE on student success.

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AUTHOR CONTRIBUTIONS

Andrew F. Mashintonio, Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Software, Supervision, Visualization, Writing – original draft | Richard H. Heineman, Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Writing – review and editing

DATA AVAILABILITY

Data for each student include the version of the lab, demographic information (gender, race, class year, transfer status, and completion of prior research), academic performance (pre- and post-test scores, final lab score, final lecture score, and final letter grade), retention in the Biology program (up to 3 years following course completion), and pre- and post-course survey responses (including self-confidence in scientific abilities, interest in pursuing science, and preferences for lab courses, each coded 1–5). All students were non-honors biology majors. Data are available from Zenodo (23).

ETHICS APPROVAL

The Kutztown University Institutional Review Board reviewed the research proposal and granted exempt status (IRB01062021).

ADDITIONAL FILES

The following material is available online.

Supplemental Material

Appendix S1 to S5 (jmbe00212-24-s0001.doc). Appendices including comparison of lab types, pre-tests, and detailed ANOVA and MANOVA results.

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