Received: 10 May 2023 | Revised: 26 October 2024 | Accepted: 20 January 2025

DOI: 10.1002/bmb.21889

ARTICLE

Biochemistry and Molecular Biology Education WILEY

Course-based undergraduate research experience impacts on student outcomes at minority-serving community colleges

Jing Zhang[1] | Sue Ellen DeChenne-Peters[2] | David Hecht[3] | Michael J. Wolyniak[4] | Misty L. Kuhn[5] | Courtney M. Koletar[6] | Nicole Galport[6] | Rebecca M. Eddy[6] | Joseph Provost[7] | Jessica K. Bell[7] | Ellis Bell[7]

[1]Department of Biochemistry, University of Nebraska-Lincoln, Lincoln, Nebraska, USA

[2]Department of Biology, Georgia Southern University, Savannah, Georgia, USA

[3]Department of Physical Sciences, Southwestern College, Chula Vista, California, USA

[4]Department of Biology, Hampden-Sydney College, Hampden-Sydney, Virginia, USA

[5]Department of Chemistry and Biochemistry, San Francisco State University, San Francisco, California, USA

[6]Cobblestone Applied Research & Evaluation, Inc., La Verne, California, USA

[7]Department of Chemistry and Biochemistry, University of San Diego, San Diego, California, USA

Correspondence
Jing Zhang, University of Nebraska-Lincoln, Department of Biochemistry, Lincoln, NE, 68588, USA.
Email: jzhang24@unl.edu

Sue Ellen DeChenne-Peters, Georgia Southern University, Department of Biology, Savannah, GA, 31419, USA.
Email: sdechennepeters@georgiasouthern.edu

Funding information
National Science Foundation, Grant/Award Number: DUE-1726932

Abstract

Course-based Undergraduate Research Experiences (CUREs) have beneficial impacts on students and the capacity to provide authentic research experiences that are accessible and beneficial to all students, especially those from Minoritized Groups. CUREs can be presented in a full semester format (cCURE) and shorter modules incorporated into laboratory courses (mCURE). In this study, protein-centric CUREs were implemented at two minority-serving Community Colleges (CCs) in introductory biology and chemistry courses. Using validated assessment tools, student self-reported gains, and institutional data, we examined student outcomes in three conditions: control, mCURE, and cCURE courses. We also examined whether there was a differential impact on student outcomes by Minoritized Group status. Our findings show that students from Minoritized Groups have improved scientific literacy compared to their White/Asian peers in the cCUREs, whereas students from Minoritized Groups in the control course had lower relative scientific literacy. There was no significant difference in STEM Career Interest between the three conditions. Most significantly, the one-year retention rate of students from the mCURE condition was 24% higher than that seen among control students. Furthermore, retention of

Jing Zhang, Sue Ellen DeChenne-Peters, David Hecht, and Michael J. Wolyniak contributed equally to this study.

students from Minoritized Groups in mCUREs was significantly higher than in control courses, whereas no significant difference was observed in White/Asian students. Taken together, these data suggest that CUREs can be an impactful practice in introductory courses at CCs, especially for students from Minoritized Groups.

KEYWORDS

community colleges, CUREs, experimental design, minoritized groups, persistence, scientific literacy

1 | INTRODUCTION

As we move forward in the 21st century, improving college STEM persistence and diversifying the STEM workforce becomes even more critical to keep up with fast-paced technological developments and help to solve complex problems. However, half of students pursuing a bachelor's degree and two-thirds of students pursuing an associate's degree in STEM either change to a non-STEM major or leave their program without a degree.[1] One major source of diversity for the STEM workforce is community colleges (CCs), where 39% of the undergraduate STEM students were enrolled in Fall 2020.[2] Therefore, the disparities in the United States STEM workforce could be partially addressed by improving CC persistence rates. One of the promising strategies to achieve this goal is through engaging students in research as early as possible.[3]

Undergraduate Research Experiences (UREs) represent a high-impact practice that improves student persistence.[4–7] They are especially transformative when engaged early in undergraduate education, and for students from Minoritized Groups.[7–9] However, the traditional apprenticeship model for such experiences is naturally limited with respect to the number of students,[10] and can also inadvertently exclude students from Minoritized Groups.[11–13] For most CC students, there are even greater challenges to participation in UREs than their peers at four-year institutions.[7,14–18] In recent years there has been a rapid expansion of UREs at CCs,[19–22] but significant barriers persist particularly because of the lack of CC faculty who have active research programs, and limited infrastructure to support undergraduate research.[23,24]

A potential solution to many of these challenges is Course-based Undergraduate Research Experiences (CUREs).[10,12] CURE courses enable students to put the scientific method into practice as well as become partners with their peers and instructors in the scientific design, discovery, and validation processes.[25–27] This results in students who are more engaged with scientific coursework, more excited about remaining in a STEM discipline, and more likely to join the STEM workforce upon graduation.[6,26,28,29] CUREs can range in length from a module within a regular laboratory course (mCURE), full semester (cCUREs), and even multiple semester experiences.[30,31] There is some evidence that the amount of time spent in a CURE can have differential impacts on student outcomes, with more time generally leading to better outcomes.[32–34]

Like UREs, CUREs improve an array of student outcomes.[34–37] Hanauer et al.[38] found with a national sample of CC students that project ownership, science identity, scientific community values, networking, and future research intent were higher in CURE courses than in traditional laboratory courses. When disaggregated by Minoritized Group status and gender, several of these variables were also higher in males and females from Minoritized Groups in CUREs than in traditional laboratory courses. Since students from Minoritized Groups enroll in higher numbers than their White/Asian counterparts at CCs,[39] working with CCs to develop, implement, and study CUREs could have especially fruitful results in generating a truly equitable scientific workforce.

Given CC's strategic role as an entry point to STEM careers – especially for students from Minoritized Groups – we need to have a better understanding of the impact of CUREs on students in CCs.[7,40] Here, as part of a study of CURE implementation at a variety of institutions, we describe the implementation and assessment of protein-centric CUREs at two minority-serving CCs: one for an Introductory Biology laboratory, and the other for a General Chemistry II laboratory. For the purposes of this project, CUREs are defined as possessing eight common elements: (1) relevance; (2) scientific background; (3) hypothesis development; (4) proposal; (5) experiments, teamwork, and collaboration, (6) reproducibility; (7) data analysis and drawing an evidence-based conclusion; and (8) presentation.[25,29,35]

We were interested in the following research questions (RQs):

1. Does instruction differ in CURE laboratories compared to control laboratory courses?
2. Do student outcomes in science process skills, retention, and STEM Career Interest differ between the CURE and control laboratory courses?
3. Are there differential outcomes for students from Minoritized Groups between CURE and control laboratory courses?

2 | METHODS

2.1 | The Malate dehydrogenase CUREs Community (MCC)

The MCC[41] is a collaborative CURE network with faculty from a wide variety of institutions engaged in undergraduate instruction. Of particular note is the work the MCC has performed with instructors to develop and implement protein-centric CURE models that were tailored and adjusted based on specific institutional infrastructure and capacities.[30,42–44]

2.2 | Participants

As part of a larger study,[30,43] we recruited three faculty members from two CCs that taught introductory biology or chemistry courses. Student self-reported demographic information is presented in Table 1. For the purposes of this study, Minoritized Groups are defined as those traditionally under-represented in STEM: American Indian/Alaska Native, Black/African American, Hispanic/Latina(o), Native Hawaiian/Pacific Islander, or two or more races/ethnicities (Table S1). When disaggregated by Minoritized Group status there is a significant difference between CCs and condition (control, mCURE, & cCURE; $p = 0.006$, Table 1), but none for gender ($p = 0.655$). Although each CC was a minority-serving institution, the CC that taught the biology course had a higher percentage of students who were from Minoritized Groups than the chemistry CC. Each faculty member taught their laboratory courses in both control and CURE conditions (see Tables S2 & S3). There were 160 students from these courses who consented and completed the evaluative instruments. The numbers of participants vary slightly by instrument.

2.3 | MCC CURE courses

The Introductory Biology course (BIOL 1101) in this study is the first course in a two-semester biology sequence that introduces the concepts of cell structure and function, cellular metabolism, heredity, and genetics. The CURE for this course was designed to focus on the

TABLE 1 Demographics by course type and community college[a].

		Control		mCURE		cCURE	
Community college	**Race and Ethnicity**[b]	**N**[c]	**Percent**	**N**[d]	**Percent**	**N**[d]	**Percent**
Biology	MG	16	84.2	7	77.8	12	66.7
	W/A	3	15.8	2	22.2	6	33.3
Chemistry	MG	26	27.7	15	20.8		
	W/A	68	72.3	57	79.2		
Total	MG	42	37.2	22	27.2	12	66.7
	W/A	71	62.8	59	72.8	6	33.3
Gender[e]							
Biology	Female	14	70.0%	5	50.0%	11	57.9
	Male	6	30.0%	5	50.0%	8	42.1
Chemistry	Female	57	58.8%	39	52.7%		
	Male	39	40.2%	35	47.3%		
Total	Female	71	60.7%	44	52.4%	11	57.9
	Male	45	38.5%	40	47.6%	8	42.1

[a]Minoritized Groups (MG) are aggregated in Table S1, White/Asian (W/A).
[b]Groups are significantly different by Race & Ethnicity, χ^2=10.178, $p = 0.006$.
[c]Four participants did not report their Race & Ethnicity, and one participant did not report their Gender (Table S1).
[d]One participant did not report their Race & Ethnicity (Table S1).
[e]Groups are not significantly different by Gender, χ^2=2.440, $p = 0.655$.

structure–function relationships of malate dehydrogenase (MDH), and was run in different semesters as both an mCURE, as well as a cCURE. The activities in both the mCURE and cCURE addressed all eight common elements of a CURE[29] (Table S2).

The General Chemistry II course (Chem 210) in this study is the second semester of the General Chemistry sequence that provides an introductory survey of a wide variety of topics. Each semester, this course was run as a mCURE that followed several 'traditional' labs to ensure compliance with articulation agreements, and to make sure students were well-trained and familiar with basic lab equipment, techniques, and lab skills before they were allowed to conduct their own individual research projects. The mCURE for this course was designed to focus on the discovery of novel inhibitors of *Plasmodium falciparum* (*Pf*) -MDH with the ultimate research objective of developing new anti-Malarial drugs. The activities in this mCURE also addressed all eight common elements of a CURE[29] (Table S3).

The faculty teaching the CUREs had extensive experience teaching at these Minority-Serving Community Colleges. The biology instructor was a white female with 12 years of teaching experience. She had broad experiences teaching CUREs prior to joining the MCC, in addition to 2 years of high school biology instruction. Both Chemistry instructors were white males. One had 14 years of teaching experience and 10 years in the biotechnology industry at the start of the study. The other had 8 years of teaching experience. Neither had any experience teaching CUREs. All instructors had experience mentoring undergraduates from Minoritized Groups in the classroom and UREs.

2.4 | Evaluative instruments

2.4.1 | Laboratory Course Assessment Survey (LCAS)

The post-only 17-item LCAS survey instrument[45] was administered to assess the differences in instruction between CURE and control courses. This is the student's perception of these three constructs. Collaboration measures collaboration between the students in the laboratory. Discovery/Relevance is a measure of how much the students perceive that the research is a real, authentic, scientific problem. Iteration measures students' perception of repeating experiments in the laboratory. Cronbach's alpha with this student sample is good (Collaboration = 0.819, Discovery/Relevance = 0.881, Iteration = 0.859).

2.4.2 | Faculty course elements survey

The 28-item faculty CURE survey was completed by faculty teaching the course at the end of the semester.[46] Each item could be scored from "no emphasis" to "major emphasis". Additionally, a faculty log developed by Cobblestone was also completed at the end of the semester (Table S6). The faculty indicated which of the nine activities students participated in as part of the course.

2.4.3 | Scientific literacy

The Test of Scientific Literacy Skills is a 28-item test of skills in scientific literacy that was administered as a pre- and post-test.[47] Percentage correct scores were calculated for each test.

2.4.4 | Experimental design

The Experimental Design Ability Test was a pre- and post-test that posed a scenario to students, which required them to design an experiment in response.[48] Faculty used a standard rubric, scoring between 0 and 10. Experimental design tests were blind-scored by 18 different MCC faculty members (for details see Callahan et al.[43]). Interrater reliability was acceptable (pre-test = 0.769, $p < 0.001$; post-test = 0.644, $p < 0.001$).

2.4.5 | Institutional data request

One-year continued enrollment and graduation information were requested from each CC, however, only the Chemistry CC submitted this information.

2.4.6 | STEM Career Interest Scale

This is a post-only 12-item survey instrument that measures STEM support, interest in STEM careers, and perceived importance of STEM.[49] Cronbach's alpha with this student sample is good (STEM Support = 0.807, STEM Career = 0.902, STEM Importance = 0.862).

2.5 | Data collection

Both CCs participating in this study obtained IRB approval prior to data collection (#IRB-2018-64 and IRB# 190823_Galport). Data were collected over a period of four semesters (Spring 2018 – Fall 2019). All student data associated with this study are available through LDbase.[50]

There were eight sections of Introductory Chemistry courses (four control and four mCURE) and four sections of Introductory Biology courses (one control, one mCURE, and two cCUREs). All instruments were administered to students by faculty participants. At the beginning of the semester, evaluation consent forms and surveys were administered, and near the end of the semester, post-test assessments were administered. The Experimental Design Ability Test was completed with pen and paper and scanned by the instructor; all other surveys were completed online.

2.6 | Data analysis

All analyses were run in SPSS version 27. Significance for statistical tests was set at $p \leq 0.05$.

General linear models were run on experimental design and scientific literacy data, including the pre-test score as a covariate, main effects for condition (cCURE, mCURE, and control) and Minoritized Group status, and an interaction term between condition and Minoritized Group status. Given the difference in Minoritized Groups between institutions (Table 1), "institution" was also included as a covariate in the general linear models. When the model was significant, Bonferroni post hoc tests were performed to determine what main effects were significantly different. If the interaction was significant, it was not possible to run a post-hoc test on the interaction in SPSS. Assumptions of the general linear model were tested before analysis commenced (Table S4).

For Likert-type data (LCAS and STEM Career Interest), the values of each item for a variable were summed and then a Kruskal-Wallis non-parametric test was performed. For the LCAS, a Kruskal-Wallis test of condition was performed on each institution independently to determine if the class conditions (control, mCURE, and cCURE) were different within each institution (RQ#1). For the STEM Career Interest, a Kruskal-Wallis test of Minoritized Group status plus condition (six categories) was run to answer RQ#3. Assumptions of the Kruskal-Wallis were tested before analysis commenced (Tables S7 and S8).

Pearson chi-squared analysis (using layered crosstabs in SPSS) was performed for dichotomous variables: retention, race/ethnicity, and gender comparisons. For race/ethnicity and gender comparisons, the cross tabs included condition (control, mCURE, & cCURE) and institution with the dependent dichotomous variable (either Minoritized Group or gender status). Due to only one institution reporting retention data, the cross tabs included condition (control, mCURE, & cCURE) and Minoritized Groups status, on the dichotomous retention variable. Due to the small number of faculty, descriptive statistics were determined for the number of faculty reporting course elements and activities.

3 | RESULTS

Table S4 contains the exact numbers used to generate each figure in the results including test statistics, *p*-values, and effect size where possible. For ease of readability, only *p*-values are reported in the main text.

3.1 | RQ 1 does instruction differ in CURE laboratories compared to control laboratory courses?

Faculty reported qualitative differences between the control and CURE courses (Tables S5 & S6). In the CURE courses, faculty reported a higher emphasis on students: input in the research process, responsibility for part of the project, reading primary literature, writing a research proposal, and presenting results orally. There was also a higher emphasis on no one knowing the outcome of the project in the CURE courses (Table S5). Similarly, more faculty reported students creating proposals, reviewing the literature, designing experiments, repeating experiments, evaluating work, and deciding future research directions (Table S6) in CUREs, compared to control courses.

Using the Kruskal-Wallis test, student perceptions of the CURE experience in the Biology CC, as measured by the LCAS,[45] showed significant differences in the levels of student discovery and relevance, with both the cCURE and mCURE having similar high mean ranks compared to the control (Table S7). Biology CC Iteration and Chemistry CC Discovery/Relevance violated the Kruskal-Wallis assumption of similar distributions, so it was not possible to use the Kruskal-Wallis to test for statistical differences. Descriptively, the Biology CC iteration mean rank was ordered highest in the mCURE, then cCURE, and lowest in the control, while the Chemistry CC discovery/relevance was greater in the mCURE than the control. There was no difference in the collaboration scale for both CCs. Iteration was not significantly different for the Chemistry CC (Table S7).

3.2 | RQs 2 & 3 do student outcomes in science process skills, retention, and STEM career interest differ between the CURE and control laboratory courses? Are there differential outcomes for students from Minoritized Groups between CURE and control laboratory courses?

3.2.1 | Test of Scientific Literacy Skills learning outcomes

Based on a general linear model analysis as described in the methods section 2.6, there was no difference in post-

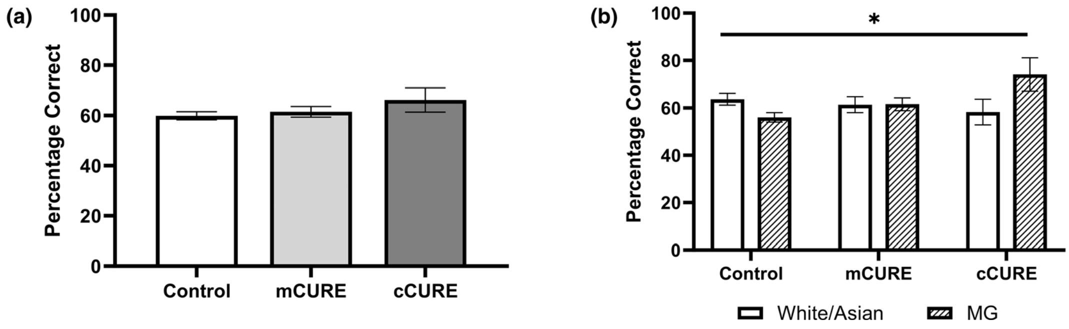

FIGURE 1 Comparison of scientific literacy skills in CURE versus control courses. A general linear model was run with prescore and institution as covariates and an interaction term for condition and Minoritized Group (MG) status. Estimated marginal means were plotted for the complete dataset (a) and the interactions (b). There was no significant difference between conditions on the Test of Scientific Literacy Skills (a. Open bar – Control, Light gray bar – mCURE, and Dark gray bar – cCURE.). However, there was a significant interaction between Minoritized Groups and condition (b. Open bar – White/Asian in Control, mCURE, and cCURE conditions. Slashed bar – Minoritized Groups in the three conditions). *$p \leq 0.05$.

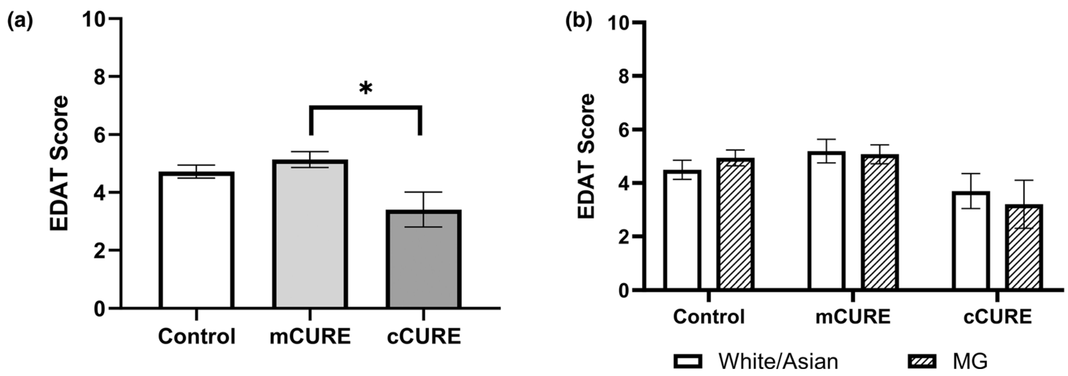

FIGURE 2 Comparison of experimental design skills in CURE versus control courses. A general linear model was run with prescore and institution as covariates and an interaction term for condition and Minoritized Group (MG) status. Estimated marginal means are plotted for the complete dataset (a) and the interactions (b). A post-hoc test found there was a significant difference between the two CURE conditions, with mCURE greater than cCURE (a, *$p \leq 0.05$. Open bar – White/Asian in Control, mCURE, and cCURE conditions). There was no significant interaction between Minoritized Groups and condition (b. Open bar – White/Asian in Control, mCURE, and cCURE conditions. Slashed bar – Minoritized Groups in the three conditions).

test scores after controlling for the pre-test score and institution (Figure 1a, $p = 0.439$). However, there was a significant interaction effect between condition, and Minoritized Group status (Figure 1b, $p = 0.018$). Students from Minoritized Groups in the control performed worse than the White/Asian students. In the mCURE, the two groups of students performed similarly, while in the cCURE students from Minoritized Groups performed better than the White/Asian students.

3.2.2 | Experimental Design Ability Test of student learning outcomes

Based on a general linear model analysis as described in methods section 2.6, there was a significant difference in post-test scores after controlling for the pre-test score and institution ($p = 0.045$). The post hoc test indicated students in the mCURE scored significantly higher than those in the cCURE (Figure 2a, $p = 0.043$). No significant interaction effect between condition and Minoritized Group status was observed (Figure 2b, $p = 0.586$).

3.2.3 | Retention after 1 year

Retention was defined as a student remaining enrolled at or graduating from their institution 1 year after participating in the mCURE or control course. Institutional data were not available for the Biology CC. Therefore, this analysis compares control and mCURE data since the Chemistry CC did not teach a cCURE. Using a layered cross-tabs SPSS analysis, there were 24% more students retained from the mCURE compared to the control

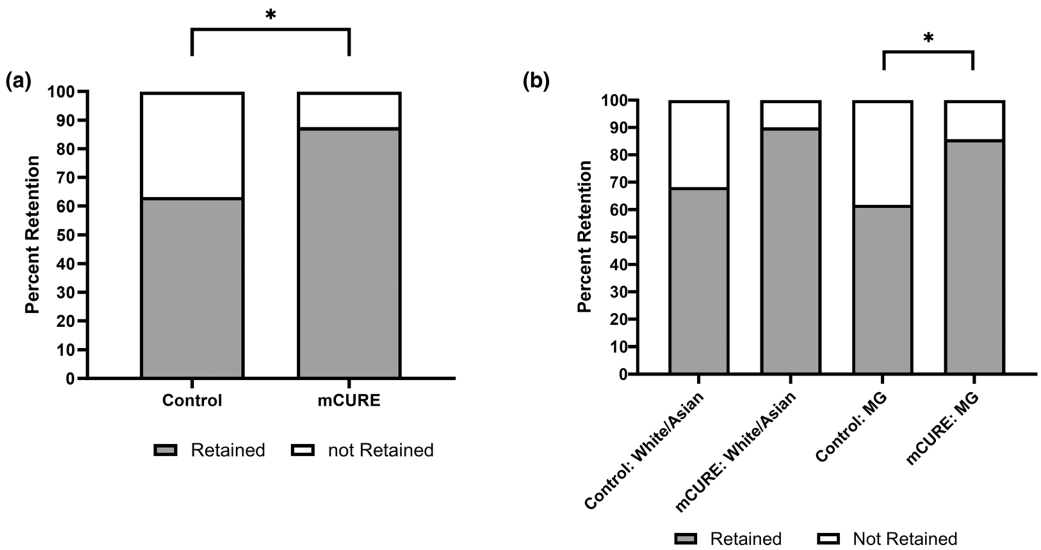

FIGURE 3 Comparison of one-year retention rates in CURE versus control courses. A layered crosstabs analysis was run to compare one-year retention rates (including graduating students) from students at the Chemistry CC. There was significantly greater one-year retention in the mCURE condition compared to the control (a. Gray bar – percentage of retained students. Open bar – percentage of not retained). When disaggregated by CURE and Minoritized Group (MG) status, there was no significant difference in White/Asian students between mCURE and control. However, there was significantly greater retention of Minoritized Group students in mCURE compared to the control (b. Gray bar – percentage of retained students in four conditions, White/Asian in Control or mCURE, and Minoritized Groups in Control or mCURE. Open bar – percentage of not retained in the four conditions). *$p \leq 0.05$.

(Figure 3a, $p = 0.005$). There was no significant effect for the White/Asian students and CURE condition (Figure 3b, $p = 0.186$). However, there were significantly more students from Minoritized Groups retained in mCUREs than in control courses (Figure 3b, $p = 0.023$).

3.2.4 | STEM career interest

The STEM Career Interest Scales measured students' interest in pursuing educational opportunities that would lead to a career in science (STEM Career), the importance they attached to a STEM career (STEM Importance), and the support they received in pursuing a STEM career (STEM Support). Based on a Kruskal-Wallis analysis, there was no significant difference for the three conditions when separated by race/ethnicity status (Table S8).

4 | DISCUSSION

4.1 | The CUREs were taught differently than the control courses

Because the MCC protein-centric CURE was implemented in two different courses at two different minority-serving CCs, it was important to determine that the CURE courses were different from traditional (control) courses with respect to the key features we used to define a CURE (see the Introduction of this work for the specific list). Students reported on the LCAS that discovery/relevance, a centerpiece of CURE courses that is largely absent from traditional courses, was significantly higher in CUREs versus control for the Biology CC (Table S7). Unfortunately, the statistical test for the Chemistry CC discovery/relevance and Biology CC iteration did not meet the Kruskal-Wallis assumption of equal distribution (Levene's test $p \leq 0.05$). Descriptively there was an increase in the mean rank on discovery/relevance for the mCURE compared to the control in the Chemistry CC (Table S7). There was no significant difference in collaboration in either CC or iteration at the Chemistry CC. In the original LCAS study,[45] there were significant differences between the traditional and CURE courses in all three scales, however, that is not always the case. Similar to Cooper et al,[51] we did not necessarily expect a difference in these two scales. Table S3 indicates that for the traditional introductory chemistry course, there were multiple iterations of semi-qualitative analyses, and repeating experiments were reported in three of the control courses, and all CURE courses (Table S6). This emphasis on repeating experiments in both control and CURE courses likely accounted for the student perception of similar iteration. Additionally, students working in small groups were emphasized in both types of courses (Table S5) which supports the students' perceptions of collaboration. The instructors of the CURE courses described a course consistent with the MCC's definition of a CURE, as well as in key indicators of course elements/activities (Tables S2, S3, S5, and S6). From these data, it appears that the CURE courses were implemented as MCC-defined CUREs compared to more traditional laboratory courses.

4.2 | Limitations of this study

While our study collected data from ~160 students, some of the individual groups were small (Table 1). To mitigate possible problems from some of the small groups in the different samples we compared, we were very careful to check the assumptions underlying each type of test, and did not report statistics where one of those assumptions was violated (two groups in the LCAS, Table S7). Given the difference in Minoritized Group status, as well as possible differences between the two CCs, we added "institution" as a covariate in the general linear model analysis. The effect sizes in the general linear model analysis were small (Table S4), which is likely tied to the small sample size. We used a non-parametric test where the data did not show normal distribution (LCAS and STEM Career Interest) which is an assumption of the Kruskal-Wallis test. The Kruskal-Wallis test does not allow for controlling the variation by institution. This was not an issue in the LCAS because we disaggregated the tests by CC to make sure that the CUREs and control classes were taught differently within each institution. Even without the institutional control, there was no significant difference for the STEM Career Interest Scales. The MCC has expanded in the last couple of years and we anticipate that as we continue to expand, we will be able to collect more CC student data. Additionally, there were several analyses that we could not perform because of institutional data that were either not available or not supplied by participating institutions. For example: we received one-year retention data for students from the Chemistry CC (control and mCURE), but not for students from the Biology CC (control, mCURE, and cCURE). Therefore, we could not compare the impact of CURE length on retention of students from Minoritized Groups', which might have revealed more important findings in addition to what we present here.

Another possible limitation of this study was that the original grant writers and developers of this study were predominantly White, as were the instructors of the courses. Since the control and CURE courses were taught by the same instructors, any unconscious biases inherent in their instruction would have little impact on this research. Additionally, there was the possibility of a change in instructor attitude because of the context of CUREs, and that might have had an impact on student outcomes. This was observed in another study where faculty indicated that their interactions with the students changed in the CURE.[52] This may be a benefit of teaching CUREs, which contributes to student outcomes, and thus would be the same for any study comparing CUREs to traditional laboratories. Given these limitations, these findings may not be generalizable to other Minority-Serving CCs. However, because of the under-study of STEM instruction at CC institutions,[40] these results are important to improving our understanding of possible CURE impacts at CC's.

4.3 | Differential effects of CUREs in CCs underscore the importance of undergraduate research toward diversifying the STEM workforce

The effectiveness of CUREs on student learning and affective outcomes was examined across these two Minority-Serving CC classrooms. The biggest impact observed was that 24% more students were retained among those participating in the chemistry mCURE course compared to control course participants (Figure 3a). In contrast, the overall retention rate for the Chemistry CC during these years remained steady with less than 1% variation across the study years (publicly available data from the institution). This finding is consistent with an increased graduation rate at a four-year institution, however that was for students who took multiple, sequential CURE semesters.[37] Furthermore, it appears that the significant difference in retention between students from Minoritized Groups in the mCURE and control courses could be driving the overall retention difference (Figure 3b). These data suggest that CUREs can be a highly effective strategy in improving the STEM persistence of participating students from Minoritized Groups at CCs. While we must be cautious to not over-extrapolate the significance of this result, it is exciting to see the potential impact of CUREs on influencing the retention of students from Minoritized Groups in STEM coursework at CCs. Given the documented successes that CUREs have had as a high-impact learning practice that invites students to think and act as "real scientists", it could be that the simple exposure of students from Minoritized Groups to such an authentic and previously-unseen scientific experience generated a sense of enthusiasm among these students, as well as the beginnings of a scientific identity.[5,6,28,29] Retention data for cCUREs were not available in this study, which is a gap to be filled in future research.

Another intriguing finding from our study was the differential scientific literacy scores by Minoritized Group status (Figure 1b). Strikingly, the performance scores of students from this population surpassed the scores of their White/Asian counterparts after taking the cCURE, reversing the results in the control students. Given the traditional barriers to accessing resources experienced by many students from Minoritized Groups,[53,54] it is possible that this population of students are receiving an educational experience that is more novel to them than it is to other students. This novelty and subsequent access to new scientific experiences, in turn, may be driving the scientific literacy gains among this population of students.

We did not observe any significant differences by student Minoritized Group status with respect to students' experimental design abilities from this work. This indicates student learning of experimental design was equivalent across groups. Interestingly, students in mCUREs scored significantly higher in their experimental design test than students in the cCURE, which is not consistent with the dataset that included all institutions.[30] Further investigation is required to elucidate this contradictory data.

Our study is one of the few studies to examine CURE outcomes in CCs or explore CURE results by Minoritized Group status. Other studies of student outcomes at CCs and/or disaggregated by Minoritized Group status used student self-assessment of learning[55] or psychosocial variables,[34,38] making direct comparisons difficult. We see similar results for objective measures of experimental design and scientific literacy in this study. Interestingly, Hanuaer (2017) found psychosocial factors, such as self-efficacy and science identity were higher in Minoritized Group CURE students than traditional classes.[34] This was also true when studying CC students.[38] Previous research has indicated that increased self-efficacy and science identity predict persistence.[56–59] This may be a partial explanation for the increased persistence found in this study.

4.4 | Opportunities for significant impact of CUREs at CCs

Our data highlight the potential CUREs have at CCs to improve year-to-year retention, especially for students from Minoritized Groups. Enrollment at CCs has been decreasing in recent years, significantly impacting budgets and funding.[60] This trend has been exacerbated by the recent COVID-19 pandemic, during which enrollment at CCs decreased 17.6% with a loss of over 150,000 students in 2020 from the previous year.[61] CUREs have the potential to be impactful at the institutional level at CCs, as even modest improvements in retention will help mitigate this detrimental effect.

Despite the significant barriers for CC students to participate in undergraduate research at the student, faculty, and institutional levels, CUREs have been successfully implemented at CCs in recent years through involvement with community partners,[14] developing relationships with four-year institutions,[29,62] and participating in the Inclusive Research Education Community[34] (a collaborative community supported by a centralized scientific and programmatic structure to address a common scientific problem). The MCC network protein-centric CURE model may represent another vehicle by which CUREs can be successfully implemented at CCs. The networked approach to the MCC allows for invaluable material and intellectual support, to make the task of developing and implementing a CURE in a new environment as straightforward as possible. Moreover, the MCC network's existing CC participants have developed pedagogical freely available models that have served them well in their own CURE experiences.

4.5 | Recommendations for designing versatile CUREs with potential for success at CCs

It is a challenge to design a CURE with the versatility to have success for any cohort of students, especially those at CCs. This study was performed in parallel with two other initiatives designed to examine the role of CURE length or collaboration between CURE courses, and outside faculty on the efficacy of the MCC CURE on student achievement.[30,43] We also published several articles on teaching the MDH CUREs.[42,44,63,64] Based on the combined findings of these studies, we propose three significant factors to consider when designing a potentially versatile CURE for CCs.

Collaboration—In the case of the MDH CURE,[43] collaboration is defined as direct interactions between faculty from another institution, and the CURE class. Collaboration can eliminate the resource disparities between student cohorts by dividing up scientific work between institutions best suited for various aspects of the project. Most importantly, collaboration brings a wide diversity of student and instructor voices to the table in implementing scientific research that can be equally engaged in by all.[43]

Modularity—A modular CURE in which instructors can select individual components that best suit their own needs can be more easily adapted to a wider range of classes. Modularity allows an instructor to make their

CURE experience a full semester, a half semester, or any other length of time. This format also enables instructors to focus on specific topics or skills of interest that best fit the demands of their target classes.[30]

Flexibility—Instructors could consider developing experiments that do not need to be done within specific time frames, thus allowing students with significant time demands and/or erratic schedules the chance to participate. Flexibility also encompasses the financial and infrastructure resources at each institution to plan experiments that can be adapted to minimize costs and maximize the utilization of existing institutional resources.

AUTHOR CONTRIBUTIONS

Zhang, DeChenne-Peters, Hecht, Wolyniak, and Kuhn prepared the manuscript. Koletar, Galport, and Eddy served as the external evaluation team that de-identified the data and created the faculty log. DeChenne-Peters analyzed the data. All authors contributed to data collection except for the external evaluation team. E. Bell was PI of the grant that provided funds for the research and was the overall director of the project. J. K. Bell, and J. J. Provost were Co-PIs of the project and helped with assessment (JKB) and CURE materials (JJP). All authors revised the manuscript, approved the version to be published, and agreed to be accountable for all aspects of the work. All authors read and approved the final manuscript.

ACKNOWLEDGMENTS

We want to thank the instructors (one of which is a manuscript author), along with their students, for participating in this study by teaching both control and CURE courses, as well as collecting the data. Additionally, we are grateful to Dr. Amy Parente for her technical assistance with figure preparation and Ms. Jessica Chantler for editorial proofreading. This work was supported by the National Science Foundation DUE-1726932.

CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in LDbase at http://ldbase.org/projects/86b50f9b-f9e0-4205-9070-acee9d3b9b30.

ORCID

Jing Zhang https://orcid.org/0000-0001-9834-5119
Courtney M. Koletar https://orcid.org/0000-0001-5108-9269
Rebecca M. Eddy https://orcid.org/0000-0002-9136-2714
Joseph Provost https://orcid.org/0000-0003-1487-1459
Ellis Bell https://orcid.org/0000-0002-8730-6664

REFERENCES

1. Chen X. Stem attrition: college students' paths into and out of STEM fields. Washington, D.C: National Center for Education Statistics; 2013.
2. AACC. Fast facts. Washington, D.C: AACC; 2022 https://www.aacc.nche.edu/research-trends/fast-facts/
3. McCook A. Two-year colleges are jumping into the U.S. research Pool. Science. 2011;333(6049):1572–3.
4. Russell SH, Hancock MP, McCullough J. Benefits of undergraduate research experiences. Science. 2007;316(5824):548–9.
5. Kuh GD. High-impact educational practices: what they are, who has access to them, and why they matter. Washington, D.C: Association of American Colleges and Universities; 2008.
6. AAAS. Vision and change in undergraduate biology education: a call to action. 2011.
7. National Academies of Sciences, Engineering, and Medicine. Undergraduate research experiences for STEM students: successes, challenges, and opportunities. Washington, D.C: National Academies Press; 2017.
8. Carter FD, Mandell M, Maton KI. The influence of on-campus, academic year undergraduate research on STEM Ph.D. outcomes: evidence from the Meyerhoff scholarship program. Educ Eval Policy Anal. 2009;31(4):441–62.
9. Hernandez PR, Woodcock A, Estrada M, Schultz PW. Undergraduate research experiences broaden diversity in the scientific workforce. Bioscience. 2018;68(3):204–11.
10. Wei CA, Woodin T. Undergraduate research experiences in biology: alternatives to the apprenticeship model. CBE Life Sci Educ. 2011;10(2):123–31.
11. Jones MT, Barlow AEL, Villarejo M. Importance of undergraduate research for minority persistence and achievement in biology. J High Educ. 2010;81(1):82–115.
12. Bangera G, Brownell SE. Course-based undergraduate research experiences can make scientific research more inclusive. CBE Life Sci Educ. 2014;13(4):602–6.
13. Carpi A, Ronan DM, Falconer HM, Lents NH. Cultivating minority scientists: undergraduate research increases self-efficacy and career ambitions for underrepresented students in STEM. J Res Sci Teach. 2017;54(2):169–94.
14. Hensel NH, Cejda BD. Embedding undergraduate research in the community college curriculum. Peer Rev. 2015;17(4):27–31.
15. Shadduck P. Comprehensive cocurricular support promotes persistence of community college STEM students. Community Coll J Res Pract. 2017;41(11):719–32.
16. Estrada M, Burnett M, Campbell AG, Campbell PB, Denetclaw WF, Gutiérrez CG, et al. Improving underrepresented minority student persistence in STEM. CBE Life Sci Educ. 2016;15(3):es5.
17. Gilmore J, Vieyra M, Timmerman B, Feldon D, Maher M. The relationship between undergraduate research participation and subsequent research performance of early career STEM graduate students. J High Educ. 2015;86(6):834–63.
18. Johnson CW, Johnson R, Steigman M, Odo C, Vijayan S, Tata DV. Appropriately targeting group interventions for academic success adopting the clinical model and PAR profiles. Educ Res. 2016;45(5):312–23.

19. Cejda BD, Hensel N. Undergraduate research at community colleges. Washington, D.C: Council on Undergraduate Research; 2009.
20. Hewlett JA. Broadening participation in undergraduate research experiences (UREs): the expanding role of the community college. CBE Life Sci Educ. 2018;17(3):es9.
21. Petersen J, Franco MM, Lall-Ramnarine S, Wang S-K. Institutionalization and sustainability of undergraduate research across disciplines at a public, urban community college: successes and challenges. Scholarsh Pract Undergrad Res. 2021; 4(3):30–9.
22. Balke V, Grusenmeyer L, McDowell J. Long-term outcomes of biotechnology student participation in undergraduate research experiences at Delaware technical community college. Scholarsh Pract Undergrad Res. 2021;4(3):5–12.
23. Nuñez A-M. Latino Students' transitions to college: a social and intercultural capital perspective. Harvard Educ Rev. 2009; 79(1):22–48.
24. Tinto V. From theory to action: exploring the institutional conditions for student retention. Higher Education: Handbook of Theory and Research. Volume 25. Dordrecht, Springer Netherlands: Science and Education Publishing Co. Ltd; 2010. p. 51–89.
25. Auchincloss LC, Laursen SL, Branchaw JL, Eagan K, Graham M, David H I, et al. Assessment of course-based undergraduate research experiences: a meeting report. CBE Life Sci Educ. 2014;13(1):29–40.
26. Bell E, Provost J, Bell JK. Skills and foundational concepts for biochemistry students. Biochemistry Education: From Theory to Practice. Volume 1337. Washington, DC: American Chemical Society; 2019. p. 65–109.
27. White HB, Benore MA, Sumter TF, Caldwell BD, Bell E. What skills should students of undergraduate biochemistry and molecular biology programs have upon graduation? Biochem Mol Biol Educ. 2013;41(5):297–301.
28. Eagan MK, Hurtado S, Chang MJ, Garcia GA, Herrera FA, Garibay JC, et al. Making a difference in science education: the impact of undergraduate research programs. Am Educ Res J. 2013;50(4):683–713.
29. Bell JK, Eckdahl TT, Hecht DA, Killion PJ, Latzer J, Mans TL, et al. Cures in biochemistry—where we are and where we should go. Biochem Mol Biol Educ. 2016;45(1):7–12.
30. DeChenne-Peters SE, Rakus JF, Parente AD, Mans TL, Eddy R, Galport N, et al. Length of course-based undergraduate research experiences (CURE) impacts student learning and attitudinal outcomes: a study of the malate dehydrogenase CUREs community (MCC). PLoS One. 2023;18(3):e0282170.
31. Thiry H, Weston TJ, Laursen SL, Hunter A-B. The benefits of multi-year research experiences: differences in novice and experienced Students' reported gains from undergraduate research. CBE Life Sci Educ. 2012;11(3):260–72.
32. Shaffer CD, Alvarez CJ, Bednarski AE, Dunbar D, Goodman AL, Reinke C, et al. A course-based research experience: how benefits change with increased investment in instructional time. CBE Life Sci Educ. 2014;13(1):111–30.
33. Winkelmann K, Baloga M, Marcinkowski T, Giannoulis C, Anquandah G, Cohen P. Improving Students' inquiry skills and self-efficacy through research-inspired modules in the general chemistry laboratory. J Chem Educ. 2015;92(2):247–55.
34. Hanauer DI, Graham MJ, SEA-PHAGES, Bobrownicki A, Cresawn SG, Garlena RA, et al. An inclusive research education community (iREC): impact of the SEA-PHAGES program on research outcomes and student learning. PNAS. 2017; 114(51):13531–6.
35. Corwin LA, Graham MJ, Dolan EL. Modeling course-based undergraduate research experiences: an agenda for future research and evaluation. CBE Life Sci Educ. 2015;14(1):es1.
36. Olimpo JT, Fisher GR, DeChenne-Peters SE. Development and evaluation of the *Tigriopus* course-based undergraduate research experience: impacts on students' content knowledge, attitudes, and motivation in a majors introductory biology course. CBE Life Sci Educ. 2016;15(4):ar72.
37. Rodenbusch SE, Hernandez PR, Simmons SL, Dolan EL. Early engagement in course-based research increases graduation rates and completion of science, engineering, and mathematics degrees. CBE Life Sci Educ. 2016;15(2):ar20.
38. Hanauer DI, Graham MJ, Jacobs-Sera D, Garlena RA, Russell DA, Sivanathan V, et al. Broadening access to STEM through the community college: investigating the role of course-based research experiences (CREs). CBE Life Sci Educ. 2022;21(2):ar38.
39. Education Data Initiative. College Enrollment & Student Demographic Statistics. Education Data Initiative; 2022.
40. Lo SM, Gardner GE, Reid J, Napoleon-Fanis V, Carroll P, Smith E, et al. Prevailing questions and methodologies in biology education research: a longitudinal analysis of research in CBE—life sciences education and at the Society for the Advancement of biology education research. CBE Life Sci Educ. 2019;18(1):ar9.
41. The Malate dehydrogenase CUREs Community (MCC). https://www.mdhcurescommunity.org
42. Callahan KP, Mans T, Zhang J, Bell E, Bell J. Using bioinformatics and molecular visualization to develop student hypotheses in a malate dehydrogenase oriented CURE. CourseSource. 2021;8. https://doi.org/10.24918/cs.2021.43
43. Callahan KP, Peterson CN, Martinez-Vaz BM, Huisinga KL, Galport N, Koletar C, et al. External collaboration results in student learning gains and positive STEM attitudes in CUREs. CBE Life Sci Educ. 2022;21(4):ar74.
44. Scheuermann NL. The influence of faculty peer network communication in the diffusion of a centralized CURE. Electronic Theses and Dissertations. 2022;2422. https://digitalcommons.georgiasouthern.edu/etd/2422
45. Corwin LA, Runyon C, Robinson A, Dolan EL. The laboratory course assessment survey: a tool to measure three dimensions of research-course design. CBE Life Sci Educ. 2015;14(4):ar37. https://doi.org/10.1187/cbe.15-03-0073
46. Lopatto D. CURE survey. CURE instructor form. Copyright 2005-2018 Grinnell college. Grinnell College. 2009.
47. Gormally C, Brickman P, Lutz M. Developing a test of scientific literacy skills (TOSLS): measuring Undergraduates' evaluation of scientific information and arguments. CBE Life Sci Educ. 2012;11(4):364–77.
48. Sirum K, Humburg J. The experimental design ability test (EDAT). Bios. 2011;37(1):8–16.
49. Tyler-Wood T, Knezek G, Christensen R. Instruments for assessing interest in STEM content and careers. J Technol Teacher Educ. 2010;18(2):345–68.

50. Bell JE, Bell JK, Provost J, DeChenne-Peters SE, Rakus JF, Parente A, et al. Malate dehydrogenase CURE Community. LDbase. http://ldbase.org/projects/86b50f9b-f9e0-4205-9070-acee9d3b9b30
51. Cooper KM, Blattman JN, Hendrix T, Brownell SE. The impact of broadly relevant novel discoveries on student project ownership in a traditional lab course turned CURE. CBE Life Sci Educ. 2019;18(4):ar57.
52. DeChenne-Peters SE, Scheuermann NL. Faculty experiences during the implementation of an introductory biology course-based undergraduate research experience (CURE). LSE. 2022; 21(4):ar70.
53. Hurtado S, Cabrera NL, Lin MH, Arellano L, Espinosa LL. Diversifying science: underrepresented student experiences in structured research programs. Res High Educ. 2009;50(2): 189–214.
54. Schultz PW, Hernandez PR, Woodcock A, Estrada M, Chance RC, Aguilar M, et al. Patching the pipeline: reducing educational disparities in the sciences through minority training programs. Educ Eval Policy Anal. 2011;33(1):95–114.
55. Genet KS. The cure for introductory, large enrollment, and online courses – proquest. 2021.
56. Espinosa L. Pipelines and pathways: women of color in undergraduate STEM majors and the college experiences that contribute to persistence. Harvard Educ Rev. 2011;81(2):209–41.
57. Graham MJ, Frederick J, Byars-Winston A, Hunter A-B, Handelsman J. Increasing persistence of college students in STEM. Science. 2013;341(6153):1455–6.
58. Linnenbrink-Garcia L, Perez T, Barger MM, Wormington SV, Godin E, Snyder KE, et al. Repairing the leaky pipeline: a motivationally supportive intervention to enhance persistence in undergraduate science pathways. Contemp Educ Psychol. 2018;53:181–95.
59. Shuster M, Curtiss J, Wright T, Champion C, Sharifi M, Bosland J, et al. Implementing and evaluating a course-based undergraduate research experience (CURE) at a Hispanic-serving institution. Interdiscipl J Probl-Based Learn. 2019; 13(2). https://doi.org/10.7771/1541-5015.1806
60. American Association of Community Colleges. Virtual listening tour report: snapshot of resilience and excellence. 2022.
61. National Student Clearinghouse Research Center. Current term enrollment estimates. Washington, D.C: Tableau Software; 2022.
62. Ashcroft J, Jaramillo V, Blatti J, Guan S-SA, Bui A, Villasenor V, et al. Building equity in STEM: a collaborative undergraduate research program to increase achievement of underserved community college students. Schol Pract Undergrad Res. 2021;4(3):47–58.
63. Provost JJ. Increasing access for biochemistry research in undergraduate education: the malate dehydrogenase CURE community. J Biol Chem. 2022;298(9):102298.
64. Martinez-Vaz BM, Mans TL, Callahan KP, Peterson CN, Bell E. Fostering student to student collaboration across institutions in a protein centric CURE. CourseSource. 2023;10. https://doi.org/10.24918/cs.2023.40

SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Zhang J, DeChenne-Peters SE, Hecht D, Wolyniak MJ, Kuhn ML, Koletar CM, et al. Course-based undergraduate research experience impacts on student outcomes at minority-serving community colleges. Biochem Mol Biol Educ. 2025;53(3): 253–64. https://doi.org/10.1002/bmb.21889