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The Impact of a Semester-Long, Cell Culture and Fluorescence Microscopy CURE on Learning and Attitudes in an Underrepresented STEM Student Population†

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Georgia Gwinnett College (GGC) is an access institution with a diverse student body, located in metro Atlanta. To strengthen research skills, teach employer-valued cell biology laboratory techniques, and increase student engagement, a semester-long, inquiry-based CURE was developed and implemented in Cell Biology with Laboratory (BIOL3400K), a sophomore-level course, which serves as a "gateway" to all upper-level biology courses. This CURE centers on the investigation of a student-chosen experimental factor on the viability of cultured, mammalian cells. Through participation in this CURE, students gain experience in cell culture, fluorescence microscopy, and viability assays, and strengthen important research skills, such as literature searches, graphing, and data analyses. The impact of this CURE on student learning gains and attitudes was assessed using pre-/post-content exams and the Colorado Learning Attitudes about Science Survey (CLASS). Our data show that all students made significant content gains. Female students made larger learning gains than male students. Additionally, minority students performed better than majority students in some content areas. Student attitudes did not change, or in some cases were slightly more negative after the CURE. Overall, this CURE had a positive impact on students by engaging them in an inquiry-based laboratory experience.

INTRODUCTION

Who we are

As an access institution, Georgia Gwinnett College (GGC) attracts diverse students with varying backgrounds. Over 50% of GGC students are first-generation college students, 12.5% non-traditional, and 52% are eligible for Pell Grants. The diversity is even more pronounced within the biology major, in which 67% of students are female, and 58% are either Hispanic, African-American, Native American, and/or mixed race. As of fall 2017, biology majors' enrollment totaled 1,231, comprising 10% of GGC's student body. Diverse populations such as ours continue to be underrepresented in STEM fields, particularly women, ethnic minorities, and persons with disabilities (1). Because a large proportion of GGC's student body is made up of these traditionally underrepresented groups in STEM graduates and STEM careers, the mission of GGC's School of Science and Technology was to create an inclusive environment in which all students could benefit from high-impact learning practices.

To address this challenge at GGC, we designed a curriculum in which STEM majors have the opportunity to engage in course-embedded undergraduate research experiences (CUREs) at each level of matriculation (2). Undergraduate research is a high-impact educational practice that can reinforce learning of course content (3), allowing all students to engage in meaningful and authentic hypothesis- or inquiry-driven research experiences.

Impact of CUREs on students

Student participation in Undergraduate Research Experiences (UREs) positively impacts skill acquisition, attitudes toward science, and aspirations to attend STEM graduate school programs (3-4). Undergraduate students engaged in research report gains in their ability to formulate research questions, collect scientific data, understand scientific research, problem solve, and identify limitations in research methods (4). Though effective, typical UREs exclude a large

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population of students through a competitive selection process, based on cumulative GPA, letters of recommendation, and prior accomplishments (5). While this serves to help universities find candidates to recruit, the process may also discourage those who could benefit the most from these experiences. Furthermore, many students at non-research intensive schools are unaware of URE opportunities (6).

An alternative to the apprentice-style UREs, CUREs are instructor-led research experiences that engage students in an inquiry-based investigation (7, 8). Through the integration of research in the course curriculum, CUREs circumvent the selection criteria UREs present while providing many of the same benefits. CUREs may have the added benefit of promoting conceptual understanding by integrating classroom and laboratory material information (9).

Students participating in CUREs show significant gains in content knowledge, attitudes toward science, confidence, and ability to analyze and interpret data (10–12). Traditionally underrepresented students benefit from their involvement in a structured research experience, as these experiences improve self-efficacy and increase persistence in STEM (13). Participating in traditional UREs or continuing in science can prove more difficult for women and underrepresented minorities (6). CUREs serve as an inclusive research model that allows under-represented students to integrate more readily as contributing members of a scientific community.

BIOL3400K CURE curriculum

Cell Biology with Laboratory (BIOL3400K) is a sophomore-level course that serves as the gateway to all upper-level biology majors' courses. Students in Cell Biology focus on cellular mechanisms, including cell cycle regulators, apoptosis, DNA replication, and gene expression.

A semester-long CURE for this course was designed to help students, with two major aims: 1) to develop and strengthen student knowledge of cell biology skills, including maintaining cell cultures, immunocytochemistry, fluorescence microscopy, micropipetting, and using the scientific method and 2) to improve student attitudes toward research by engaging them in the scientific process. Given the body of literature supporting the positive impact of CUREs, we anticipated gains in student learning and more positive attitudes toward research after participation in this curriculum. Emerging research suggests that CUREs are especially beneficial to students from underrepresented groups in STEM (13). To determine whether this semester-long CURE particularly benefited underrepresented students, we investigated gender and race/ethnicity differences in student learning and attitudes in response to the curriculum.

The semester-long CURE (14) (Table 1) is a 12-week project designed to increase student engagement and give students ownership of their project by asking them to choose an experimental factor to test on the viability of PtK2 cells. Details on implementing the CURE, including supply lists, sample worksheets and protocols, and suggestions for adapting the curriculum for different types of courses and institutions are found in (14).

Briefly, the project is divided into two modules; the first module (Module 1) tests the effects of their factor on cell viability, and the second (Module 2) investigates the mechanism of these effects by examining mitosis and cell death.

Module 1

Students were encouraged to select factors whose effect on PtK2 cells was unknown or to hypothesize effects on PtK2 cells based on previous studies. The only limitations were that the factor must be polar and that it could be legally obtained by all students (i.e., no prescription drugs or alcohol). Students found research articles to support chosen factors and then, following a group discussion, one factor per group was selected for investigation. Examples of student-chosen factors included colloidal silver, pomegranate juice, and herbal teas. Following a literature search on the chosen factor's impact on cell viability in other cell lines and/or model systems, the group generated a hypothesis as to the effect of the factor on the viability of PtK2 cells.

During these first six weeks of the semester, students learned cell culturing techniques to maintain their PtK2 cells. All student groups practiced sterile technique, passaging of cells, and trypan blue assays on cells treated with 1:1,000 dilution of lemon juice, which provided an opportunity for student learning through trial and error.

TABLE 1.
A semester-long CURE, using cell culture and fluorescence microscopy techniques.

Weeks	Module	Laboratory and Research Skills
1–6	*1. Cell Culture and Trypan Blue Exclusion Assays:* Students will design experiments to test the effect of a chosen experimental factor on PtK2 cell viability. Students will have at least two attempts at their experiments.	• Experimental design, graphing, and data analysis • Mammalian cell culture • Cell viability assays • Cell dilution calculations
7–12	*2. Fluorescence Microscopy:* Students will determine the effect of their chosen experimental factor on cell cycle distribution and/or apoptosis using fluorescence microscopy.	• Experimental design, graphing, and data analysis • Fluorescently labeling cells • Fluorescence microscopy

Next, students chose a concentration of their experimental factor to test. Each student group cultured two PtK2 flasks, one "experimental" treated with their factor, and one "control" treated with phosphate-buffered saline (PBS). Based on trypan blue assay results, students conducted a second trial using either the same, increasing, or decreasing concentrations of the factor used in trial 1. Following both trials, students used hemocytometers to collect data about cell viability. These data were graphically presented, comparing control versus experimental groups.

Module 2

In the second module, which comprised the final five weeks of the semester, students used fluorescence microscopy to investigate the effect of their factor on mitosis or apoptosis. Each group received a chamber slide seeded with PtK2 cells. Two "experimental" chambers were treated with their factor and the remaining two chambers served as "controls" treated with PBS. After 48 to 72 hours of incubation with the factor, students used immunocytochemistry to visualize microtubules (anti-tubulin), actin (phalloidin), and DNA (DAPI). Following staining, each group captured images in control and factor-treated chambers using a fluorescence microscope. They examined the effects of the factor on the organization of DNA, tubulin, and actin to quantitatively determine the degree of factor-induced apoptosis or mitosis in the cultures.

This semester-long CURE concluded with each student compiling their lab-inquiry experience in a comprehensive lab report. This lab report is similar to a research publication, requiring students to incorporate multiple experiments with multi-panel figures.

METHODS

Laboratory protocols

All laboratory exercises were performed in accordance with the ASM Guidelines for Biosafety in Teaching Laboratories (15). PtK2 cells (Biosafety Level 1) are an adherent cell line derived from male rat-kangaroo (*Potorous tridactylus*) epithelial kidney tissue (16). PtK2 cells (ATCC; Catalog# CCL-56) were cultured in DMEM/F12K media (Corning; Catalog# MT10092CM) supplemented with 10% heat-inactivated fetal bovine serum (Gibco; Catalog# 16140071), 1% antibiotic/antimycotic solution (Hyclone Catalog# SV3007901) and cultured at 37°C in a CO_2 water jacket incubator. Each week, PtK2 cells were detached with trypsin (Corning; Cat # MT25052CV) and were then washed and re-plated at a density of 0.5×10^6–1×10^6 cells/mL.

Cell viability was measured using two methods: trypan blue exclusion assay and examination of chromatin structure, visualized by DAPI staining. To determine cell viability and concentration, cell suspensions were diluted 1:1 with 0.4% trypan blue (Gibco, Catalog # 15250-061), loaded onto disposable hemocytometers (Invitrogen, Catalog # C10228) and analyzed using the Countess II automated cell counter. To analyze cell morphology, mitosis, and apoptosis, PtK2 cells were plated on chamber slides (Thermo Scientific, Catalog# 12-565-17), treated with an experimental factor and analyzed by immunohistochemistry. Each step described below was performed at room temperature (RT), and after each incubation, cells were washed three times with PBS. After media was removed from the chamber slides, 3.7% formaldehyde in PBS was added for 7 minutes to fix the cells. After washing, 0.5% Triton-X 100 in PBS was added for 7 minutes to permeabilize the cells. To block non-specific binding, 1% bovine serum albumin (BSA) was added, and slides were stored at 4°C. To visualize tubulin, anti-tubulin-α at a 1:400 dilution in 1% BSA (Biolegend, Catalog #627906) was added for 40 min. Next, to visualize actin, phalloidin at a 1:20 dilution in 1% BSA (Cell Signaling Technology, Catalog #8953S) was added for 20 minutes. Lastly, chambers were removed, and mounting media with DAPI (Life Technologies, Catalog # P36935) was added and coverslips applied. Images were collected using the EVOS FL cell imaging system.

Timeline of CURE implementation and assessment

The semester-long CURE (14) (experimental) was piloted in two sections of BIOL3400K in fall 2015, while the other five sections completed two, unrelated, half-semester CUREs (control): the "Yeast and UV radiation" CURE (17) and the fluorescence microscopy-based "Cancer Drug Study" (18) (Table 2). The new CURE was implemented in two sections in fall 2015 and three sections in spring 2016. During this time, the CLASS (Colorado Learning Attitudes about Science Survey) for Biology (19) survey was administered at the beginning and end of each semester to gauge the impact of participation in one or two CUREs on student attitudes toward research. Beginning in spring 2017, a 20-question content exam with questions mapped to specific learning outcomes and laboratory skills and a demographic survey were administered at the beginning and end of the semester, in addition to the CLASS. The Georgia Gwinnett College Institutional Review Board approved this assessment methodology and related instruments.

Assessment instruments and methodology

Results from the pre-/post-content exam (Appendix 1) and the CLASS-Biology (19) instrument were analyzed. Demographic categorization of responses to both instruments consisted of the following binary factors: Gender (M vs. F), Race/Ethnicity (white [non-Hispanic] vs. non-white and/or Hispanic) based on NSF demographic categories (20), and Representation in STEM (well-represented [non-Hispanic white or Asian] vs. underrepresented [African-American/Black and/or Hispanic/Latinx and/or American Indian and/or Alaskan Native]) (1).

TABLE 2.
Timeline of semester-long CURE implementation and assessments.

Semester	CURE Implemented	Pre-/Post- Assessments
Fall 2015	*Control (5 sections):* yeast module (half-semester); cancer drug study (half-semester) *Experimental (2 sections):* Semester-long CURE	CLASS
Spring 2016	*Control (3 sections):* yeast module (half semester); cancer drug study (half semester) *Experimental (3 sections):* Semester-long CURE	CLASS
Fall 2016	Semester-long CURE in all 7 sections	CLASS
Spring 2017	Semester-long CURE in all 6 sections	CLASS, content exam, and demographic survey
Fall 2017	Semester-long CURE in all 7 sections	CLASS, content exam, and demographic survey
Spring 2018	Semester-long CURE in all 6 sections	CLASS, content exam, and demographic survey

Data analysis, content knowledge

Data filtering was required to ensure that post- and pre-student responses were paired correctly, demographic data were available, and that no responses were invalid. The resulting data set consisted of 149 students over three semesters who had pre- and post-content quiz results and met all the filtering criteria. A breakdown of the categorization is as follows: 1) Gender: 66 Male, 83 female; 2) Race/Ethnicity: 47 white (not Hispanic), 102 non-white and/or Hispanic; 3) Representation in STEM: 76 well-represented, 73 underrepresented. The group of 20 content assessment questions was partitioned into two categories, Topics and Skills, and then further divided into subcategories (Table 3).

The basic hypothesis test used was a *t*-test on the differences between post- and pre-scores with the null hypothesis being that the population mean of the differences is zero, i.e., no indication that content knowledge increased during the course. Both one-sample and two-sample *t*-tests were used where appropriate and were tested at the 0.05 significance level.

Letting μ_d represent the population mean of the differences d = Post-test Score – Pre-test Score, such that reported positive d values reflect greater post-test scores while negative d values reflect greater pre-test scores, the null and alternative hypotheses for the one-sample *t*-test are:

$$\mathbf{H_0}: \mu_d = 0; \mathbf{H_1}: \mu_d \neq 0$$

For the 2-sample *t*-tests, the null and alternative hypotheses are:

$$\mathbf{H_0}: \mu_{d,1} = \mu_{d,2}; \mathbf{H_1}: \mu_{d,1} \neq \mu_{d,2}$$

where $\mu_{d,1}$ is the population mean of the differences d for group 1 and $\mu_{d,2}$ is the population mean of the differences for group 2.

TABLE 3.
Content assessment question grouping.

Categories	Subcategories	Questions
Topics	Cell Culture	1–5
	General Lab Tools	6–9
	Microscopy	10–20
Skills	Content	1, 10–11
	Lab Tools	6–9
	Technique	2–4, 16–20
	Application	5, 12–15

Data analysis, attitudes toward science

Data filtering was required to ensure that post- and pre-student responses were paired correctly, demographic data was available, and that no responses were invalid. The resulting data set consisted of 161 students (~65% of the original respondents) over three semesters who had pre- and post-attitudinal survey results and met all of the filtering criteria. A breakdown of the categorization is as follows: 1) *Gender*: 70 male, 91 female; 2) *Race/Ethnicity*: 49 white (not Hispanic), 112 non-white and/or Hispanic; 3) *Representation in STEM*: 80 well-represented, 81 underrepresented.

In addition to the categorical demographic factors outlined above, the 32 questions (Likert-type items) were grouped in multiple ways. Different groupings (19) have been identified and are shown in Table 4.

In the grouped analysis of attitudinal survey questions, some questions needed to be "flipped" or "reversed" to be consistent with other similar questions. This was due to the manner in which the survey questions were posed. The questions whose Likert item responses were flipped in the grouped analysis were: 5, 6, 10, 11, 15, 19, 21, 23, 25, 30, 31, and 32.

Approaches to analyzing Likert-type survey data varies in the literature, from ordinal logistic regression and para-

TABLE 4.
CLASS attitudinal assessment question groupings.

Group	Questions
Real World Connection	2, 12, 14, 16, 17, 19, 25
Enjoyment (Personal Interest)	1, 2, 9, 12, 18, 27
Problem Solving: Reasoning	8, 14, 16, 17, 24
Problem Solving: Synthesis and Application	3, 5, 6, 10, 11, 21, 30
Problem Solving: Strategies	7, 8, 20, 22
Problem Solving: Effort	8, 12, 20, 22, 24, 27, 30
Conceptual Connection (Memorization)	6, 8, 11, 15, 19, 23, 31, 32

metric hypothesis tests such as the *t*-test to nonparametric hypothesis tests such as the Wilcoxon signed-rank test and Mann-Whitney-Wilcoxon (MWW) test. Our Likert-type survey responses vary among the categories: Strongly Disagree, Disagree, Neutral, Agree, and Strongly Agree and thus are ordinal in nature. We assessed the distribution of changes in attitude between pre-survey results and post-survey results and whether the overall change in attitude ($\bar{d}$) was positive or negative for a particular question or set of questions, i.e., identified whether there was a fundamental shift in attitude. We used nonparametric hypothesis testing approaches: a one-sample Wilcoxon signed-rank test on differences post–pre and two-sample MWW tests for demographic factor analysis.

RESULTS

Content knowledge

Aggregated pre-/post-content test data from spring 2017, fall 2017, and spring 2018 were analyzed to assess the impact of the semester-long CURE on student learning. As shown in Table 5, where ($\bar{d}$) represents the pre-test score subtracted from the post-test score, post-content test scores were significantly higher than pre-test scores, showing a 7.17-point increase on a 20-point exam (36% increase) (columns 2 and 3). In the *Cell Culture* exam subcategory, students earned 2.02 more points out of a possible 5 on the post-test, relative to the pre-test (40% increase). Higher post-test scores were also observed in the other exam subcategories: 43.8% higher in *Microscopy* (4.38-point increase out of a possible 10), 57% higher in *Content* (1.71-point increase out of a possible 3), 19.5% higher in *Lab Tools* (0.78-point increase out of a possible 4), 35% higher in *Techniques* (2.79-point increase out of a possible 8), and 38% higher in *Application* (1.9-point increase out of a possible 5).

Data were further examined to determine whether demographics influenced test scores. Analyses show that female students performed significantly better than male students (column 4), overall (Full Test), and in the *Application* subcategory. Furthermore, non-white students performed better than white students in the *Content* subcategory (column 5). No differences in test scores were observed between the Well-Represented in STEM and Underrepresented in STEM populations.

TABLE 5.
Pre-/post-content test scores.

Test Subcategory	$\bar{d}$	1-sample *t*-test *p* value Pre-Test vs. Post-Test	2-sample *t*-test *p* value Male vs. Female	2-sample *t*-test *p* value White vs. Non-White	2-sample *t*-test *p* value Well-Represented vs. Underrepresented
Full Test	7.17	$<1.0\times10^{-12}$*	0.030*	0.589	0.156
Cell Culture	2.02	$<1.0\times10^{-12}$*	0.266	0.146	0.682
Microscopy	4.38	$<1.0\times10^{-12}$*	0.089	0.789	0.086
Content	1.71	$<1.0\times10^{-12}$*	0.867	0.042*	0.991
Lab Tools	0.78	$<1.0\times10^{-12}$*	0.119	0.462	0.229
Technique	2.79	$<1.0\times10^{-12}$*	0.426	0.922	0.273
Application	1.90	$<1.0\times10^{-12}$*	0.015*	0.629	0.474

Comparison by Gender (male vs. female), Race/Ethnicity (white [non-Hispanic] vs. non-white and/or Hispanic) and Representation in STEM (well-represented [non-Hispanic, white, or Asian] vs. Underrepresented [African-American/Black and/or Hispanic/Latinx and/or American Indian and/or Alaskan Native]).

* = $p < 0.05$

Attitude toward science

The CLASS survey was used to determine whether participation in the CURE changed student attitudes toward research. To examine specific aspects of student attitudes toward science, CLASS data can be analyzed by grouping similar statements into categories. To this end, CLASS survey responses were analyzed by question category (Table 6), as determined by Semsar *et al.* (19).

Before implementation of the current semester-long cell culture CURE in BIOL3400K, two six-week CUREs were carried out within a semester: the "Yeast and UV Radiation" CURE (17) and the "Cancer Drug" CURE (18). To begin, fall 2015 and spring 2016 CLASS attitudinal data were compared between students enrolled in sections of BIOL3400K that conducted two unrelated CUREs and students enrolled in sections of BIOL3400K implementing the semester-long CURE. No statistically significant differences in attitudes pre vs. post were observed in the students participating in two CUREs compared with students participating in the single CURE (data not shown).

All BIOL3400K students from fall 2016 to spring 2018 participated in the semester-long CURE. Examination of responses to CLASS question categories from this time are shown in Table 6, where e ($\bar{d}$) represents the differences between average pre- and post-survey on four-point Likert-type scale responses. A positive e ($\bar{d}$) indicates a shift in student responses toward a more positive attitude, while a negative e ($\bar{d}$) shows students responses shifting toward a more negative attitude. As a whole, students responded more favorably to Enjoyment (Personal Interest) questions and more negatively to Problem Solving: Strategies and Conceptual Connections (Memorization) questions at the end of the semester. No differences were found between male and female student responses. Non-white and white students showed variation, with non-white students responding more positively to Enjoyment (Personal Interest) and more negatively to Problem Solving: Effort questions (Table 6, Fig. 1). Lastly, Problem Solving: Reasoning responses from Underrepresented in STEM students were more positive than Well-Represented in STEM students.

DISCUSSION

BIOL3400K students at GGC participated in an inquiry-based, semester-long CURE that focuses on cell viability in mammalian cells. Students were challenged to ask scientific questions, develop hypotheses, design experiments to test their hypotheses, and report their findings in both oral and written form. Over the course of the semester, students acquired both research skills (primary and secondary literature research and experimental design) and laboratory skills (mammalian tissue culture and fluorescence microscopy).

TABLE 6.
Pre-/post-attitudinal scores by category.

CLASS Survey Category	$\bar{d}$	Wilcoxon Signed Rank Test *p* Value Overall Data Set	2-Sample MWW Test *p* value Male vs. Female	2-Sample MWW Test *p* Value White vs. Non-White	2-Sample MWW Test *p* Value Well-Represented vs. Underrepresented
Real World Connection	0.004	0.464	0.415	0.438	0.027
Enjoyment (Personal Interest)	0.054	0.031*	0.461	0.015*	0.876
Problem Solving: Reasoning	–0.051	0.085	0.803	0.485	0.01*
Problem Solving: Synthesis and Application	0.011	0.609	0.421	0.907	0.263
Problem Solving: Strategies	–0.090	0.038*	0.431	0.187	0.602
Problem Solving: Effort	–0.036	0.179	0.281	0.031*	0.581
Conceptual Connections (Memorization)	–0.092	0.006*	0.134	0.158	0.771

Comparison by Gender (Male vs. Female), Race/Ethnicity (White [Non-Hispanic] vs. Non-White and/or Hispanic) and Representation in STEM (Well-represented [Non-Hispanic White or Asian] vs. Underrepresented [African-American/Black and/or Hispanic/Latinx and/or American Indian and/or Alaskan Native]).
MWW = Mann-Whitney-Wilcoxon
* = $p < 0.05$

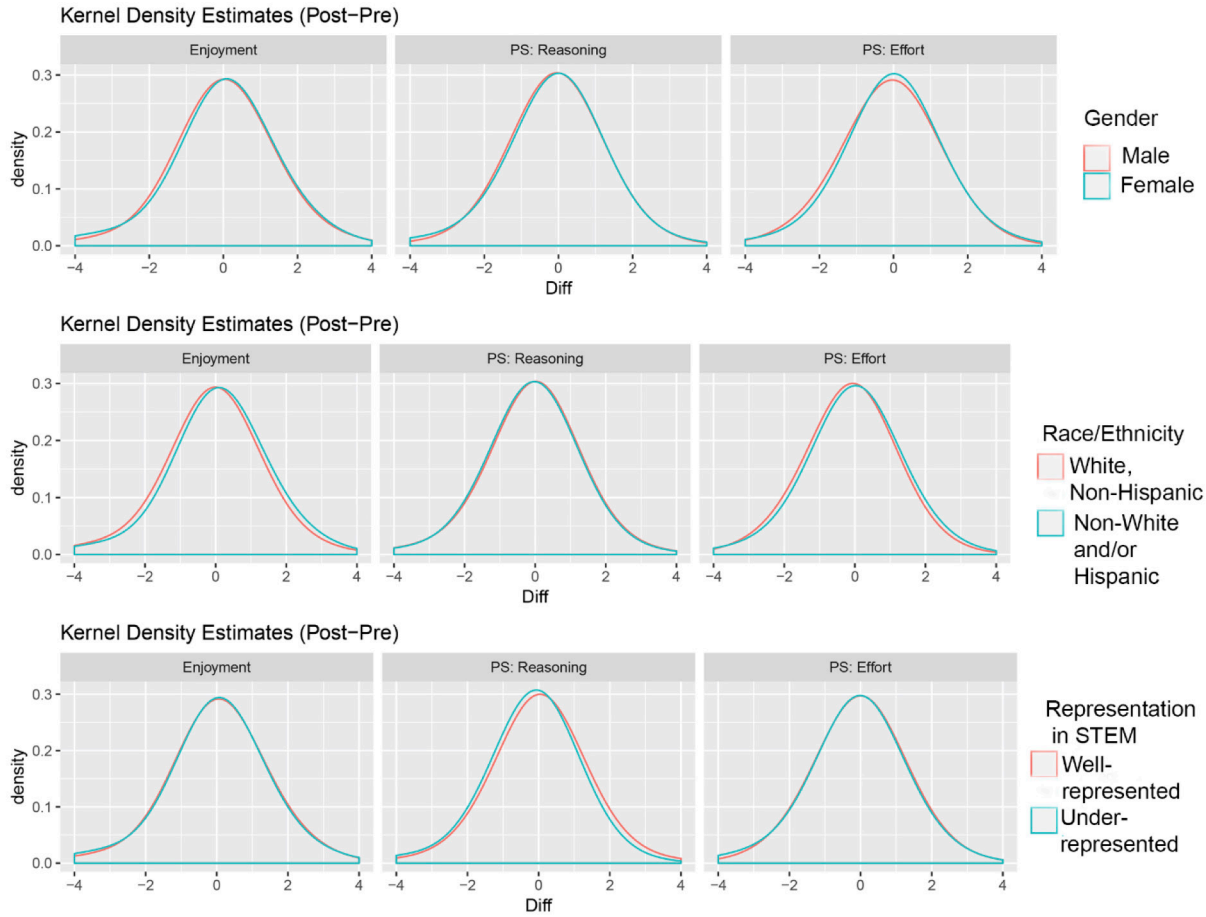

FIGURE 1. Kernel Density Estimates, CLASS Categories. Kernel density plots CLASS question categories Enjoyment, Problem Solving: Reasoning, and Problem Solving: Effort. Comparison by Gender (Male vs. Female), Race/Ethnicity (White [Non-Hispanic] vs. Non-White and/or Hispanic) and Representation in STEM (Well-represented [Non-Hispanic White or Asian] vs. Underrepresented [African-American/Black and/or Hispanic/Latinx and/or American Indian and/or Alaskan Native]).

Semester-long CUREs have been shown to have a positive impact on students by improving content learning gains, attitudes toward science, understanding of experimental design, and long-term gains such as increasing intentions to pursue graduate education or careers in science (22–24). One study measuring student-reported learning gains demonstrated that the longer students spent on a CURE over the course of the semester, the higher the reports of learning (9). Our data showed that students participating in this semester-long CURE made significant content gains (Table 5); however, lack of a true control during the latter half of the study limits our ability to determine the extent to which the CURE contributed to these gains. Our analyses also showed that women made more content gains than men overall and that non-white students made more gains than white students in some exam subcategories (Table 5). Together, these data suggest that CUREs are particularly beneficial to traditionally underrepresented populations in STEM classes, supporting the use and development of more CUREs at GGC and at institutions with similar student body profiles. Development of CUREs at institutions with large populations of minority students also aligns with recommendations to improve underrepresented student persistence in STEM by a National Institute of General Medical Sciences and Howard Hughes Medical Institute joint working group (21). As a future study, faculty are interested in using higher-level Bloom's instruments to better understand the impact of the CURE on student learning.

CURE faculty observed improved student accuracy and speed of aseptic cell culture techniques as the semester progressed. At times, the student-chosen factor did not change cell viability compared with control flasks, which initiated conversations that included terms like "failure" or "didn't work." This presented opportunities to reinforce the idea that scientific research is a process that requires repeated laboratory experiments and often acquires data that are unanticipated, but still valid. Some students experienced bacterial contamination in cell culture flasks, allowing additional group discussions on the importance of replicates, repeating experiments, and learning proper aseptic technique. Although some students did not favor researching and choosing their factor, many students expressed great interest in doing "real science," despite struggling with their experiments. This is consistent with a recent article (22)

highlighting the importance of accepting "failure" in shifting to a growth mindset and its relation to science pedagogy.

One aspect of this study focused on the ability of our Cell Biology CURE to positively impact student attitudes toward science. Our data show no significant differences between students exposed to one semester-long CURE compared with two half-semester-long CUREs (data not shown). This suggests that participation in one versus multiple CUREs does not alter student attitudes. When only examining attitudinal data from students who completed the semester-long CURE, attitudinal shifts were minimal, including a slight increase in personal enjoyment of research and more negative attitudes toward conceptual connections and confidence in problem solving.

Georgia Gwinnett College has a very diverse student population, with a high percentage of non-traditional students and students from underrepresented groups in STEM. Given the diversity of our student population, we also asked whether our CURE differentially impacts students in relation to race, ethnicity, or gender. Our study shows there were some race/ethnicity-based and sex-based differences in relation to attitudes toward sciences, problem solving, and enjoyment of the CURE. In general, these attitudinal shifts were slightly negative after participation in the CURE. Faculty teaching CUREs at GGC are interested in following student attitudes as they progress through higher-level classes to see whether their attitudes change, as it is possible that students will begin to see the value of the CURE's impact on their learning and attitudes and will become more positive about CUREs as they progress through the curriculum.

Despite performing better than or as well as majority students on the content exam, women and minority students demonstrated slightly more negative attitudes at the end of the semester. One possibility is that gender and/or race and ethnicity can influence student interpretation of CLASS questions. The original CLASS instrument (23), developed for physics students, was validated with a majority (80%) white student population, containing an equal number of males and females. The Biology CLASS instrument used in this study (19) was validated using 39 students: 10 males and 29 females. Race and ethnicity data for these students were not included in the manuscript. Efforts have been made to develop attitudinal assessments validated with diverse student populations for use in K–12 STEM pedagogy research (24) to avoid implicit bias. Our findings raise questions about the best ways to assess the attitudes of underrepresented students in higher education STEM education research, and the need for diversity to be considered more in instrument validation processes.

It is important to acknowledge that CUREs can be perceived differently by different students (7) and to develop CUREs with student diversity in mind. Our data support the idea that CUREs enhance some student learning, particularly for women and underrepresented student populations. This semester-long CURE can serve as a model for cell biology labs at other institutions, especially those serving diverse and underserved student populations, and can be adopted to increase student engagement and content knowledge in core cell biology concepts.

SUPPLEMENTAL MATERIALS

Appendix 1: Content assessment, attitudinal assessment, and demographic questions

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