


Flying in the Face of Adversity: a *Drosophila*-Based Virtual CURE (Course-Based Undergraduate Research Experience) Provides a Semester-Long Authentic Research Opportunity to the Flipped Classroom

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A call for the integration of research experiences into all biology curricula has been a major goal for educational reform efforts nationally. Course-based undergraduate research experiences (CUREs) have been the predominant method of accomplishing this, but their associated costs and complex design can limit their wide adoption. In 2020, the COVID-19 pandemic forced programs to identify unique ways to still provide authentic research experiences while students were virtual. We report here a complete guide for the successful implementation of a semester-long virtual CURE that uses *Drosophila* behavioral assays to explore the connection between pain and addiction with the use of an at-home “lab-in-a-box.” Individual components were piloted across three semesters and launched as a 100-level introductory course with 19 students. We found that this course increased science identity and successfully improved key research competencies as per the Undergraduate Research Student Self-Assessment (URSSA) survey. This course is ideal for flipped classrooms ranging from introductory to upper-level biology/neuroscience courses and can be integrated directly into the lecture period without the need for building a new course. Given the low cost, recent comfort with virtual learning environments, and current proliferation of flipped classrooms following the 2020 pandemic, this curriculum could serve as an ideal project-based active-learning tool for equitably increasing access to authentic research experiences.

KEYWORDS CURE, virtual, active-learning, backward design, pain, addiction, *Drosophila*, biology, science identity, research

INTRODUCTION

For students to develop critical thinking skills as learners, scientists, and citizens, they must participate in activities that apply both practical research techniques and the scientific process in real-world contexts (1, 2). Traditional mentored research experiences are integral to biology education, as they provide a high academic challenge, active collaborative, experiential learning, enriching educational experience, intense student-faculty interaction, and a supportive campus environment (3). These activities, however, are not widely available to all students due to high student-faculty ratios and challenges integrating authentic research

experiences into the biology curricula. Given the growing comfort-level with virtual learning environments post-COVID and the subsequent wide movement toward prerecorded lectures, a unique opportunity exists to integrate a project-based authentic research experience directly into the classroom's weekly 3-hour lecture period in either an in-person or virtual setting. By strategically focusing on behavioral assays as experimental outputs, costs can also be dramatically reduced.

Considerable research has demonstrated the benefits of undergraduate research experiences on student learning, including the development of domain expertise, acquisition of team-based skills, increased understanding and respect for the research process, acquisition of problem-solving skills, practice and refinement of communication skills, and increased self-confidence, personal growth, independence, and tolerance (4–10). Comparable benefits are seen across race and gender and across institutional types, including research universities, master's-level institutions, and teaching colleges (11). Furthermore, these experiences are

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thought to especially benefit women and underrepresented students due to fostering of mentor-mentee and peer-peer relationships (12–14).

Despite these recommendations, however, its often impractical to expand this to an entire undergraduate population (15, 16). Historically, the incorporation of research experiences into the undergraduate curriculum has been in the form of mentored one-on-one research apprenticeships in research laboratories (5, 11). However, the high student-faculty ratio prevents all students from participating, often at the cost of diversity and equity in training (17, 18). A solution to this problem is to integrate authentic research experiences into a course-based setting.

Course-based undergraduate research experiences (CUREs) are a scalable solution for providing authentic research experiences to undergraduates while still fulfilling the benchmarks set by the National Research Council (8, 19). CUREs are easier to scale up and offer research for credit instead of relying on self-selection (20). This is especially the case for students of low socioeconomic backgrounds who often are unable to participate in extracurricular research activities due to employment. Additionally, CUREs can be integrated into introductory courses to engage first- and second-year students in research earlier to exert a larger influence on academic and career choices (21). Despite the numerous implementations and successes of CUREs, they are still widely underused.

Since CUREs generally rely on teaching laboratories, it can be challenging to find dedicated space to create a scalable authentic research experience for some institutions. Further, CUREs are often stand-alone electives which can disincentivize their adoption because they may dilute a packed curricula or may be perceived as too time-consuming for faculty with limited time. One way to overcome this is to create viable authentic research experiences that can be integrated directly into the lecture period and/or allow students to conduct research at home. As higher education begins to place a greater priority on quality online education, virtual CUREs can overcome several of these challenges and have already seen some success (22).

Here, we report the implementation of a virtual CURE (vCURE) geared toward first-year undergraduates at Rutgers University Camden, a primarily undergraduate institution with a diverse and nontraditional STEM population (90% commuters, 55% first-generation/low income, 28% African American, and 16% LatinX). The course allowed students to explore the intersection between the opioid epidemic and pain using the model organism *Drosophila melanogaster* at a cost of less than \$15/student. Self-reported data indicate that this course improved science identity and key research competencies as assessed by the Undergraduate Research Student Self-Assessment (URSSA) survey (23, 24). The manuscript describes the structure and function of this 3-credit vCURE model and provides detail to adopt it in its entirety or adapt it to fit specific needs. Uniquely, our vCURE could be implemented in a hybrid manner as a project-based research experience that serves as the active-learning

component of flipped classrooms ranging from Biology 101 to upper-level neuroscience. We also describe details of tapping into the proliferation of virtual scientific conferences/webinars as a method to provide students a unique training opportunity often missed because of the financial constraints of attending in-person conferences. It is our hope that this vCURE model could be widely and easily adopted to increase access to authentic research experiences at any stage of the undergraduate curricula.

INTENDED AUDIENCE

The intended audience is first-year biology majors, but it is designed to run at any undergraduate level. Additionally, we also had a few nonbiology majors, suggesting it could work with a range of undergraduates.

LEARNING TIME

This is a semester-long project-based 3-credit biology elective across 15 weeks but can be scaled down depending on the context. Each week, students spend 1 hour watching prelecture videos, 3 hours in synchronous sessions, and 1 to 6 hours in asynchronous sessions working on the project or assignments.

PREREQUISITE STUDENT KNOWLEDGE

There is no prerequisite knowledge, and students do not need experience working with *Drosophila*. For our iteration of this class, most students were in their first year with minimal biology background.

LEARNING OBJECTIVES

Our overall goals for this course were the following:

1. Students will develop a greater science identity.
2. Students will gain valuable research experience from a virtual setting.

We sought to achieve this with the following learning objections. The comprehension-based objectives were:

1. Describe introductory neuroscience concepts in relation to the research project.
2. Describe the molecular mechanisms of addiction.
3. Describe the molecular mechanisms of pain.

The application-based objectives were:

4. Critique, troubleshoot, and engage in a virtual team of researchers to collaboratively complete a research project.

5. Collect data with *Drosophila melanogaster* behavioral techniques.

The synthesis-based objectives were:

6. Navigate the scientific literature to develop a research project virtually.
7. Engage with recent scientific discoveries related to the research project.
8. Critique scientific talks from a national conference and identify how talks relate to the project.

PROCEDURE

This course integrates experiential learning into a flipped-classroom by implementing *Drosophila*-based research into lecture periods. It is designed as a 3-credit 15-week course that meets twice/week but can be modified to run in a shorter curriculum. While this course was run in and is ideal for a virtual setting, the original concept was developed for an in-person environment to place a research-based project into a traditional 3-credit flipped classroom without the need for including an additional corequisite lab.

Each week is broken into 2 days: (i) content days where in-class discussions/activities focus on understanding required content and (ii) lab meetings where in-class discussions/activities focus on completing a semester-long research project. Student assignments/activities are broken into individual work and group work. All work and activities are designed to mirror that which would be experienced in a traditional research lab.

Below are the information/materials necessary to run this course within the scope of students learning the neuroscience of addiction and chronic pain. However, the components can be used for other topics, and other protocols could be adapted to the content of interest. Thus, we have written the manuscript to facilitate faculty implementing the curriculum in its entirety or identifying individual components to adopt/modify/supplement their courses.

Materials

Students will need the following:

1. Computer/internet access.
2. Video conferencing platform such as Zoom for synchronous meetings.
3. Cloud-based word processor/database/presentation programs, such as those provided by Google Docs for collaborative work.
4. Communication platform for instant conversation/troubleshooting, such as Slack.
5. Learning management software for classroom organization, such as Canvas.
6. “Lab-in-a-box” that includes *Drosophila* and all necessary tools for students to carry out the behavioral experiments in the semester-long research

project. This “lab-in-a-box” is described within the Lab Manual (Appendix 4) and Assembly Plan (Appendix 5).

Student instructions

Students are responsible for both individual and group work in the form of leading synchronous/asynchronous discussions, quizzes, presentations, and hands-on research activities. Detailed student instructions for each component can be found in the course syllabus (Appendix 1), course schedule (Appendix 2), journal club worksheet (Appendix 3), lab manual (Appendix 4), and peer assessments (Appendix 6).

Faculty instructions

Below are the instructions, commentary, and advice for the successful implementation of the course. Further commentary on each component can be found in the syllabus annotations (Appendix 1).

Designing the research project. Faculty should design a semester-long research project that is approachable by students in the format of a traditional CURE. We recommend using a backward design that starts with a straightforward research question/hypothesis/prediction and includes simple experimental design/variables. These can be constructed, as done here, by using simple *Drosophila* behavioral assays. Once these are established, course content can be developed. For our project, we utilized four simple behavioral assays to study the impact of chronic pain on the development of addiction in *Drosophila*.

Given the limited in-class time, project plans should be developed prior to starting the course. See the lab manual for details on our project (Appendix 4). Faculty can use our project design to explore the same question or a similar question, build a different project with the included behavioral assays, or develop a different research project with other behavioral assays. We encourage student input when developing the project (i.e., exploring sleep, diet, or other factors on addiction), but the practical challenges of limited time may require the project to be fully developed by the faculty member. We suggest using simple-to-approach behavioral assays, including the negative geotaxis, sensitivity, tolerance, and Capillary Feeder (CAFE) assays to assess addiction. If built around simple and consistent behavioral assays as the dependent variable, faculty can explore a range of relevant topics as independent variables. Importantly, exploring an unknown instead of confirmatory experimentation instills greater buy-in from students and is the driving essence of authentic CUREs.

Conducting the research project. We include details for building a lab-in-a-box at the cost of \$15/student (Appendix 5, lab-in-a-box assembly plan). If deviating from our project design, it is essential to account for every potential need, since reshipping supplies can be cumbersome. Since flies need to be flipped regularly, we suggest

waiting to send the lab-in-a-box until the experiments begin.

While students are broken into groups of 4 to 5, all students are collecting data as a single replicate (i.e., every student will conduct all experiments instead of a single group being assigned a single assay). This redundancy accounts for environmental and technical variables introduced by different students in different homes. It is expected that not all students will successfully obtain data, so making it clear that failure is common will prevent incentives for students to deviate from a responsible conduct of research to ensure data integrity. Although invertebrate studies do not need to be approved by the Institutional Animal Care and Use Committee (IACUC), some students may wish to abstain from certain experimental procedures due to personal ethics or discomfort with flies. These students can conduct the experiments virtually with peers to still gain the underlying concepts and knowledge of the experiment. We also recommend reserving time to discuss the ethics of animal research. Each group is assigned a different research presentation. To foster ownership and project management skillsets, these groups should coordinate data consolidation and analysis for their particular presentation by creating a central cloud-based data repository.

Content days. The first session each week is a lecture period reviewing essential content. Critically, the content should be identified with backward design focused on the goals of the research project and need not be comprehensive of the entire field or topic. For example, we identified critical knowledge necessary to understand the project (basic neuroscience, neuroanatomy of pain/addiction, *Drosophila* biology, etc.) and designed the course content (weekly quizzes, science news discussion, and traditional lecture content) (Appendix 2, course schedule).

Lab meeting days. The second session each week includes group-based journal clubs, presentations, and technique instruction (Appendix 2, course schedule). The first few weeks reinforce concepts in experimental design, responsible conduct of research, basic statistical analysis, and presentation of data. The following weeks focus on group-led journal clubs related to the project. Once students have received their lab-in-a-box, faculty use this time to teach experimental techniques. We recorded these sessions for future reference and used break-out rooms for troubleshooting. Once students begin collecting data, these sessions are used for the group-led research presentations.

Suggestions for determining student learning. Rubrics are included with all assignments. We used traditional formative assessments to measure comprehension-based objectives. To measure application- and synthesis-based objectives, we designed activities and assessments that mirror those which would be seen in a traditional research lab (proposal defense, research-in-progress talks, thesis defense, conference debriefs, journal clubs, etc.). Importantly, we did not assess students on their ability to complete the project, but instead, on their engagement in

and understanding of the project since failure in experimentation is common.

Sample data. As seen in Discussion, students received As and Bs on the content quizzes, indicating they understood the primary content point. We include a sample journal club worksheet (Appendix 8) indicating students could understand the major components of assigned research articles even if they had some trouble with unfamiliarity with certain experimental techniques due to limited science literacy at this stage. Student presentations were comprehensive and appropriate for their stage, indicating they were collaboratively conducting experiments and analyzing data sufficiently to complete this project in a virtual setting.

Safety issues. The procedures and content were designed to comply with the American Society of Microbiology Guidelines for Biosafety in Teaching Laboratories. Although none of the items in this lab-in-a-box are hazardous, we recommend students attend a lab safety training. We utilized an online CITI Right-To-Know lab safety training program. These boxes contain live *Drosophila*, low-concentration ethanol (max 50% ethyl alcohol [EtOH] in comparison to hand sanitizer at 60% EtOH), and small glass capillary tubes.

DISCUSSION

Field testing

This course was initially conceived as a strategy to integrate a low-cost CURE into an in-person flipped classroom. Whereas flipped classrooms often contain a series of active learning exercises and CUREs are often their own separate entity, our curriculum can be plugged into a traditional flipped lecture-based course. This allows for the expansion of CUREs while avoiding the common impediments to them since any flipped course could integrate this CURE model for its active-learning component. As such, we built this CURE around a popular 400-level course that ran in two previous semesters, called “The Neuroscience of the Opioid Epidemic.”

We initially piloted the virtual aspect of this CURE in the summer of 2020 in partnership with the nonprofit research hub eCLOSE, which had developed a fully virtual bioscience research curriculum with a *Drosophila*-based lab-in-a-box for students ranging from middle school to college. During that summer, four Rutgers Camden undergraduates participated in this program with 49 students from other institutions to pilot the lab-in-a-box curriculum and identify methods to adapt it to our pain/addiction course plan. We combined this virtual component with other mechanisms ideal for the lecture period that were developed and tested in our more traditional 300-level CURE and launched our lecture-based virtual CURE in the fall of 2020. Thus, components of this virtual CURE have been field-tested over several semesters, piloted in the summer of 2020, and fully tested in a 100-level undergraduate course with 19 honors

students during the fall of 2020 (see the demographics for the 12 who participated in the survey in Table 1).

Evidence of student learning

Learning objectives 1 to 3 were evaluated with formative assessments of weekly quizzes focused on determining the comprehension of content material. Learning objective 1 was evaluated from week 5 to 11 quizzes (88% mean, 79% to 91% range). Learning objective 2 was evaluated from week 3 and 14 quizzes (87% mean, 85% to 89% range). Learning objective 3 was evaluated from week 2 and 12 quizzes (89% mean, 86% to 91% range). These grades demonstrate that students had a good/excellent comprehension of necessary material.

Learning objectives 4 to 5 were evaluated with application-based presentations and research-related activity assessments. Learning objective 4 was evaluated by research presentation grades (93% mean, 89% to 96% range). Since each group is responsible for presenting the next iteration of the project presentations (i.e., group 1 presents the proposal, group 2 presents the research in progress, group 4 presents the thesis defense), successfully presenting relies on inter- and intragroup collaboration in a virtual setting. Indicating further virtual collaboration, 100% of students engaged with a shared Google document to enter/analyze collected data. Indicating sufficient collaboration on critiquing and troubleshooting the project, presenting groups received feedback from 89% of students and received an average of 96% for their class score, and individual students had a 96% average for their peer evaluation grade. Learning objective 5 was assessed by the number of students successfully collecting data for each experiment. A total of 89% (17/19) of students chose to receive the lab-in-a-box. There was a high success rate in collecting data for the core experiments (94% obtained data from the climbing assay, 59% obtained data from the sensitivity assay, and 47% obtained data from the tolerance assay). Only 6% of students, however, obtained data from the more complex CAFE, assay perhaps suggesting an upper limit of the types of assays that can be effectively conducted at home.

Learning objectives 6 to 8 were evaluated with presentations and activities focused on assessing a student's ability to synthesize new information from the course. Learning objective 6 was evaluated using the journal club presentation grade (89% average), which measures the group presentation of the paper, the journal club worksheet grade (93% average), which measures the individual understanding of the paper, and the journal club moderator grade (94% average), which measures the level of audience engagement during the presentation. Learning objective 7 was evaluated using the Monday News Presentation grade (96% average), which measures ability to engage with recent science news related to the project, and the Canvas Forum Moderator grade (98% average), which measures the level of class engagement. Additionally, 63% of the class engaged in weekly online conversation around the

science news. Learning objective 8 was evaluated with the conference debrief presentation grade (94% average). These data suggest that students were able to synthesize information from their research experience.

To assess goals 1 and 2, we used two validated survey instruments in a pre-/posttest design. The pretest was given at week 4, before students received their lab-in-a-box but after becoming familiar with the course to allow for the specific evaluation of the course's research component. Of the 19 students, 12 took part in both the pre- and posttests. We collected demographic data indicating first-generation college student status, major, age, gender, and year (Table 1). To ensure that these students were well matched, we confirmed that they did not have any previous research experience but had similar levels of engagement in extracurricular science-related activities (Table 2).

We first assessed science identity (goal 1), which measures how much a student identifies as a scientist or science trainee (23). This measure positively correlates with success, academic retention, and whether the student enters a science occupation. On a 1 to 7 Likert scale, science identity significantly increased in the full cohort (Fig. 1A; $P = 0.0463$). We saw no differences when comparing first-generation to non-first-generation students. Interestingly, science identity was significantly less in females than males at both the pre- and post-time points (Fig. 1B; $P < 0.05$ and $P < 0.001$, respectively).

We also measured science identity discrepancy, which assesses the difference between how a student perceives themselves in relation to how they perceive that others see them in science. This comparison creates a scale where more positive numbers indicate that a student rates themselves less than they think others would rate them in science. Thus, positive values could be interpreted as a measure of “science imposter syndrome,” while negative values could be interpreted as a measure of “science underdog status.” While no changes were seen in the full cohort comparing pre- to post-time points, we did see gender differences at each time point (Fig. 1C). At both the pre- and post-time points, males had neutral science discrepancies (Fig. 1D). Females, however, had greater discrepancy scores than males at both time points, suggesting greater levels of imposter syndrome (Fig. 1D). There were no differences between first-generation and non-first-generation students (Table 2).

We then used the URSSA to evaluate whether our vCURE was a successful research experience (goal 2) (24). This validated 34-question survey reports 4 critical research measures, thinking and working like a scientist, personal scientific gains, scientific skills, and researcher attitudes/behaviors. We found significant increases in all four measures across the total cohort (Fig. 2) but no differences between first-generation and non-first-generation students or between genders (Table 2). Notably, we found no differences among any groups in their baseline research confidence, which is a measure of self-efficacy to

TABLE I
Student demographics^a

Group	Demographics				Major				Yr				Science experience			
	No.	Mean age (%)	Male (%)	Female (%)	Low SES (%)	URM (%)	Biology (%)	Health sciences (%)	Other (%)	1st (%)	2nd (%)	3rd (%)	Previous research experience (%)	Attended science-related museum or watched science-related documentary outside classroom (%)	Had a conversation about a science related topic with family or friends (%)	Read a science-related book or magazine outside the classroom (%)
Full cohort	12	19.75	42	58	25	8	25	58	17	75	8	17	0	83	100	58
Not first gen	6	18	67	33	0	0	17	67	17	83	17	0	0	83	100	50
First gen	6	21.5	17	83	50	17	33	50	17	67	0	33	0	83	100	67

^aSES refers to socioeconomic status. Science experience is the percentage of students involved in those associated science-related activities. URM, underrepresented minority; gen, generation.

TABLE 2
Statistical analyses^{a,b}

Group Measure	Full cohort						Male						Female						Non-first gen (NFG)						First gen (FG)						P value																					
	Pre			Post			Pre			Post			Pre			Post			Pre			Post			Pre			Post			Pre			Post																		
	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Mean	SD	SD	Pre vs post	F	M	F	M vs F	FG v NFG	M vs F	FG vs NFG								
Stets	4.75	1.36	5.33	0.89	5.80	0.45	6.20	0.45	4.00	1.29	4.71	0.49	5.17	1.17	5.67	0.52	4.33	1.51	5.00	1.10	0.0463	0.1778	0.1403	0.0143	0.3094	0.0003	0.2073																									
SP	2.88	1.13	3.08	1.09	3.45	0.89	3.50	1.21	2.46	1.15	2.79	0.97	3.17	0.85	3.21	0.89	2.58	1.37	2.96	1.34	0.3535	0.8276	0.3859	0.1412	0.3949	0.2829	0.7105																									
SD	1.04	1.38	0.58	0.96	0.05	0.54	-0.20	0.84	1.75	1.37	1.14	0.59	0.75	1.37	0.42	0.90	1.33	1.45	0.75	1.07	0.2128	0.5083	0.3188	0.0263	0.4895	0.0084	0.5733																									
RC	3.79	0.70			3.85	0.63			3.75	0.79			3.92	0.58			3.67	0.83						0.8197	0.5603																											
URSSA Thinking	2.50	0.94	4.23	0.74	2.53	1.29	4.08	1.07	2.48	0.71	4.34	0.45	2.44	1.11	4.08	0.92	2.56	0.83	4.38	0.55	0.0000	0.0297	0.0001	0.9421	0.8296	0.5673	0.5211																									
Gains	2.50	1.09	4.08	0.68	2.50	1.55	4.03	0.77	2.45	0.86	4.12	0.66	2.25	1.05	4.00	0.64	2.75	1.17	4.17	0.76	0.0000	0.0262	0.0018	0.9465	0.4541	0.8402	0.6901																									
Skills	2.22	1.05	3.72	0.76	2.40	1.34	3.62	0.96	2.08	0.88	3.79	0.67	2.03	1.07	3.42	0.63	2.40	1.10	4.01	0.82	0.0001	0.0917	0.0000	0.6309	0.5628	0.7245	0.1878																									
Attitudes	2.00	0.94	3.53	0.85	2.05	1.28	3.48	0.99	1.96	0.72	3.57	0.83	1.65	0.87	3.17	0.50	2.35	0.94	3.90	1.02	0.0000	0.0087	0.0001	0.8848	0.2056	0.8574	0.1457																									

^aMeans ± standard deviation were used for all survey instrument measurements, and P values were used for all comparisons. STETS refers to the science identity questionnaire developed by Stets et al. (23) in 2017 that measures science identity (SI), science identity prominence (SP), and science identity discrepancy (SD). RC indicates the research confidence questionnaire. URSSA is the Undergraduate Research Student Self-Assessment. Measures developed by Weston and Laursen (24) in 2015 that measures thinking and working like a scientist, personal scientific gains, improvement of scientific skills, and improvement of researcher attitudes/behaviors. Pre refers to week 4 of the course prior to receiving the “lab-in-a-box”. Post refers to week 15 which was the end of the class.

^bGen, generation; M, male; F, female.

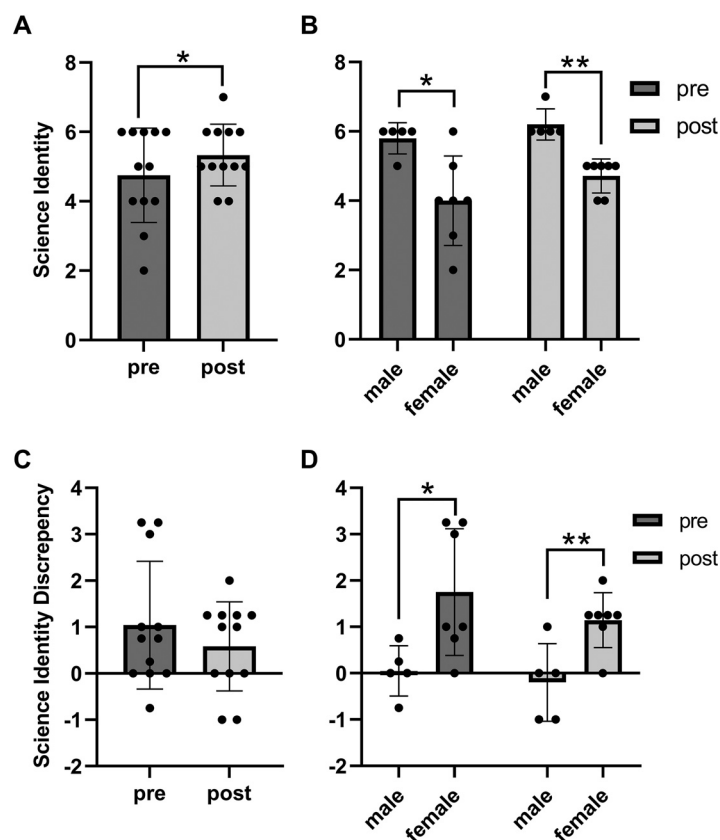


FIG 1. Science Identity Measures. This survey instrument assesses goal 1. (A and B) Science identity of full cohort at pre- and post-time points (A) and male versus female at pre- and post-time points (B). (C and D) Science identity discrepancy of full cohort (C) and male versus female at pre- and post-time points (D). Pre-time point assessments occurred during week 4 of the course prior to receiving the “lab-in-a-box,” while post-time point assessments occurred during week 15 at the end of the experimentation period. $n = 12$ for the full cohort (7 females, 5 males) with * indicating $P < 0.05$ and ** indicating $P < 0.001$ from paired and unpaired t tests.

perform science-related tasks (Table 2). Combined with the gender differences in science identity discrepancy, we posit that while female students within our class may feel less skilled than those around them, a quantified self-assessment of their own ability suggests otherwise. These gender differences are not necessarily surprising, since females in several fields indicate greater imposter syndrome than males (25, 26). However, it reinforces the importance of still pursuing systemic improvements that encourage women in STEM regardless that the National Institutes of Health no longer consider women underrepresented in the biomedical sciences. While we did not see any differences in first-generation students, the URSSA assessments may instead suggest that this vCURE can be effective regardless of familial college experience.

Possible modifications

With the inevitable proliferation of flipped classrooms after COVID-19 forced biology faculty to prerecord lectures, we believe there is an unprecedented opportunity for integrating CUREs directly into the lecture period as the active learning component of a flipped classroom. This model could be widely adopted in either a virtual or in-person capacity.

Further, the recent comfort with virtual settings could expand the accessibility of research experiences by adopting this vCURE into a range of settings such as summer bridges or research experiences for undergraduates (REUs) without the need for expansive infrastructure or large budgets. Combined with its low cost and virtual capacity, this vCURE could be a low-cost method to foster science identity prior to a student entering their first college-level biology course. While we ran this as a full 15-week course, the modular aspect of it could be scaled up or down depending on the size of the class and be used in large entry-level or smaller upper-level courses. Further, the behavioral assays could be adopted for studies exploring a wide range of research topics outside the realm of pain and addiction.

One of the defining characteristics of immersing oneself fully into the scientific community is interacting with peers and colleagues at scientific conferences. This essential experience is often restrictive to undergraduate students due to financial constraints. As conferences move back to in-person settings, webinars and virtual seminars will likely continue as opportunities for applying course content outside the classroom.

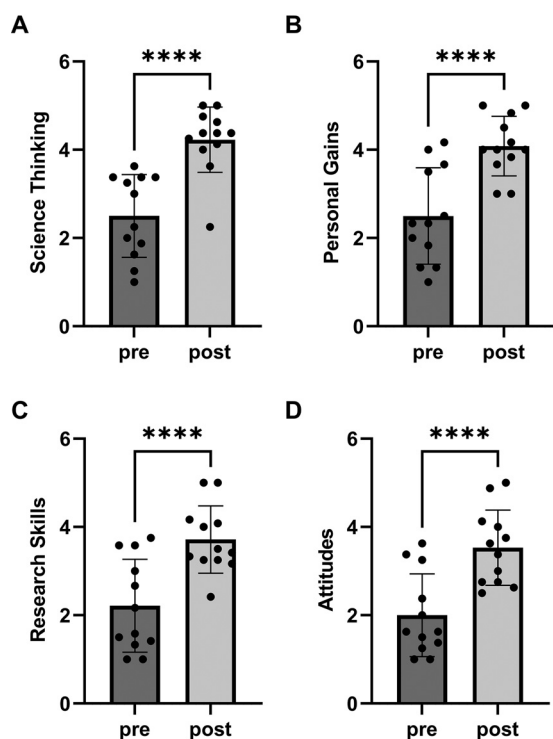


FIG 2. URSSA scores. This survey instrument assesses goal 2. Scores from the Undergraduate Research Student Self-Assessment for the full cohort. (A to D) Thinking and working like a scientist (A), personal scientific gains (B), scientific skills (C), and researcher attitudes/behaviors (D). Pre-time point assessments occurred during week 4 of the course prior to receiving the "lab-in-a-box," while post-time point assessments occurred during week 15 at the end of the experimentation period. $n = 12$ for the full cohort with **** indicating $P < 0.0001$ from paired and unpaired t tests.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.4 MB.

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