Peer-Reviewed Article

Integration of Inquiry-Based Experiences Department-Wide: An Example from Biology Curriculum

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Abstract

Inquiry-based course experiences provide a scalable and equitable way to engage students in research. In this study, we describe how we introduced inquiry-based experiences to 10 lower-division and upper-division courses across the biology curriculum at California State University, Dominguez Hills (CSUDH), a regionally comprehensive public university serving the diverse population of the Los Angeles Basin of California. Student survey data suggest this redesign effectively developed students' scientific skills and nurtured their sense of belonging. This project illustrates how inquiry-based experiences can be implemented sustainably across institutional context.

Introduction

One of the best ways to learn science is by doing science. Doing science introduces students to the scientific process, helps them hone transferable skills like data analysis and written and oral presentation, and encourages them to self-identify as scientists (Brownell & Kloser, 2015). Often, students do science through undergraduate research, which is defined as inquiry done by undergraduates that contributes to broader knowledge (What Is CUR's Definition of Undergraduate Research?, n.d.). Undergraduate research is hugely impactful to students (Linn et al., 2015; Lopatto, 2007, 2010; Russell et al., 2007), and it is considered one of the 11 high-impact pedagogical practices of universities and colleges (O'Donnell et al., 2015). However, students most typically engage in undergraduate research through internships or independent programs, which can typically only serve a small number of students and can thus perpetuate equity gaps (Bangera & Brownell, 2014).

Inquiry-based experiences in the classroom offer an alternate way to engage students in undergraduate research at scale (Auchincloss et al., 2014; Linn et al., 2015; Spell et al., 2014). Inquiry-based experiences (IBEs) are designed to reflect the scientific cycle of posing and answering questions, thus allowing students to take some or complete ownership of the research process (Rissing & Cogan, 2009; Weaver et al., 2008). IBEs can vary in the extent of student ownership (Fig. 1), and they are often loosely grouped in three categories: guided inquiry, open inquiry, and course-based undergraduate research experiences. In guided inquiry approaches, the instructor poses the question and students develop the experimental design with instructor guidance. In open inquiry approaches, the students develop their own question and experimental approach, and in course-based undergraduate research experiences (CUREs), students iterate on previous work and collect broadly relevant, new data (Beck et al., 2014, 2023; Cooper et al., 2019).

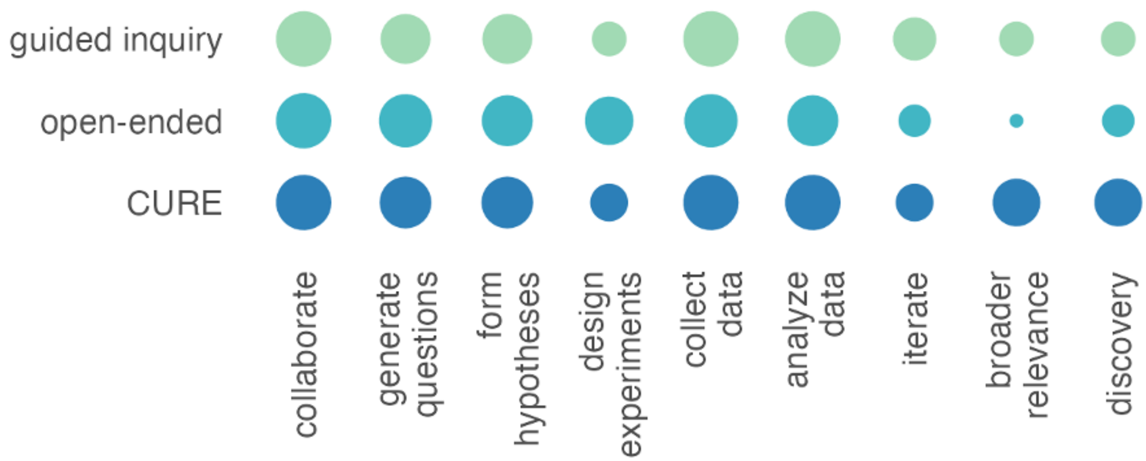
Across the three types of IBEs, students apply their content knowledge to novel problems, develop multiple skills such as experimental design and scientific communication, and work collaboratively with their peers (Auchincloss et al., 2014; Buchanan & Fisher, 2022; Corwin et al., 2015). These benefits of IBEs contribute to student success. IBEs have been shown to strengthen student mastery over content (Rissing & Cogan, 2009), heighten student enjoyment and motivation for the subject matter (Pavlova et al., 2021; Shaffer et al., 2014), strengthen student confidence in their scientific abilities (Brownell et al., 2015), and help bridge equity gaps (Rodenbusch et al., 2016; Shapiro et al., 2015).

Given the many benefits of IBEs, the Biology department at California State University, Dominguez Hills (CSUDH) initiated a redesign of our laboratory courses to incorporate more inquiry-based practices. CSUDH is a predominantly-undergraduate urban university in the Greater Los Angeles Region in southern California, United States. As an open-access university, CSUDH serves the diverse population of the region—nearly 70% of students are Latino and 11% are Black, 48% of students are first-generation, and 60% of students are Pell Grant eligible.

Upon graduation, the average CSUDH Biology student has spent more than 300 contact hours in biology lab courses. However, nearly all these hours are spent in "cookbook" labs, in which students follow a pre-determined protocol to arrive at a pre-determined result. Our primary focus was to redesign all four of our required lower-division

Figure 1

A continuum of inquiry-based experiences



Note. Shown are the diversity of inquiry-based experiences, including guided inquiry (which two of our redesigned classes followed), open-ended inquiry (five classes), and course-based undergraduate research experience (CURE; three classes). Circle size reflects the average extent to which a given component of the inquiry process is present in each type of inquiry-based experience, as determined by the faculty redesigning the course. Iteration, broader relevance, and discovery follow definitions outlined by Auchincloss et al. (2014).

biology labs (Fig. 2) to help retain the many undergraduates who leave science early in their career (Bakshi et al., 2016; Chen, 2013; Russell et al., 2007). In addition, we redesigned six of our 14 upper-division lab courses. As a result of this initiative, the average Biology student will now typically enroll in seven redesigned lab courses (equivalent to 250 contact hours) throughout their undergraduate degree (Fig. 2). In this study, we discuss our approach to the redesign, describe our redesigned labs, and share results on the student experience and project success.

Redesign Process

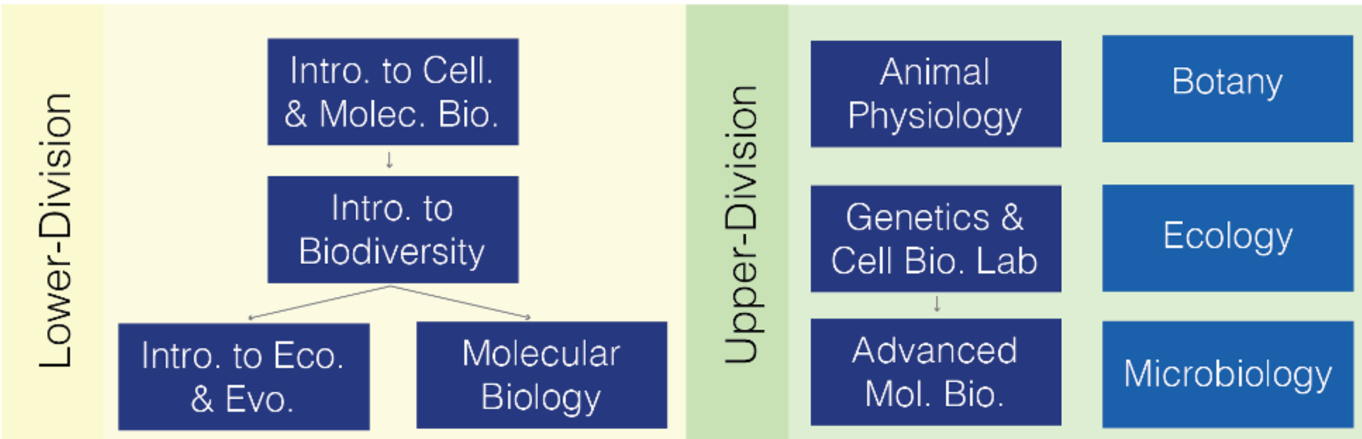
For each of the 10 lab courses included in this project, we asked the faculty member who most often taught the course to join our project and redesign the class. Thus, all participating faculty had intimate experience with the lab course; most had taught the accompanying lecture class as well.

The project commenced with three major benchmarks for success: student retention in the major, student efficacy in their scientific abilities, and student sense of belonging in the major. In the summer of 2020, all eight participating faculty met to collaboratively decide on project-level learning objectives aligned with these benchmarks. Our learning objectives were: students should be able to use the scientific method, communicate effectively, work effectively in teams, recognize the diversity of participants within the scientific community, and apply quantitative skills.

Then, we identified specific activities that can help students to achieve these learning objectives. For example, effective scientific communication

Figure 2

The 10 courses redesigned as inquiry-based labs



Note. Most biology students would take at least seven of these courses; one likely set is indicated in dark blue. Arrows indicate pre-requisite structure within each division.

requires students to learn how to generate figures and tables, how to find and parse the primary scientific literature, and how to write a lab report. Because more than half of our full-time faculty were involved in the initial stages of this project, we were able to build connections and scaffolding through classes (McDonald et al., 2019). Students engaged with increasingly complex and challenging aspects of the learning objective as they progressed through the curriculum (see Appendix 1). Finally, we developed rubrics for lab reports, oral lab presentations, literature review, and teamwork for use by all lab instructors.

Our overall methodological approach was to provide pedagogical flexibility to participating faculty within the context of these collaboratively-designed learning objectives and scaffolding. We asked faculty to work largely independently to redesign their lab courses and to identify activities and class structures that suited their course content and teaching style.

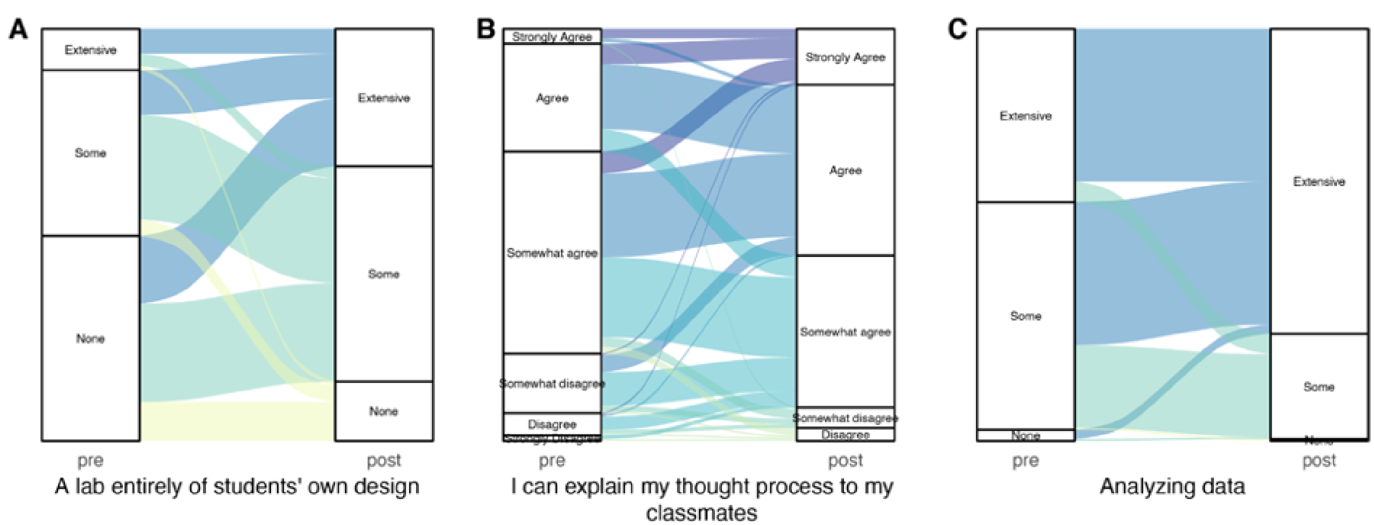
Redesigned classes were launched across two years from Fall 2020 to Spring 2022, during which our university was employing primarily online instruction. Since then, CSUDH has resumed face-to-face instruction, and the redesigned labs are now being deployed in-person.

Evaluation

To help evaluate our project's efficacy, we surveyed students enrolled in redesigned labs at the start and end of the semester in a pre-post fashion leveraging a variety of validated instruments (Appendix 2). These surveys asked students to: 1) self-report their level of experience with a variety of lab-course related features (e.g. "A lab or project in which only the instructor knows the outcome" and "work in small groups") as well as lab-associated scientific skills (e.g. "read primary literature," "analyze data," and "present results orally") using items from the Survey of Undergraduate Research Experiences (Lopatto, 2007), 2) describe their perception of who does and does not conduct science leveraging the Scientist Spotlight assessments (Schinske et al., 2016), and 3) report the strength of their social context, their peer-to-peer and peer-to-instructor relationships in the course (e.g. "The instructor seems to care about me" and "I feel comfortable asking for help from classmates") (Walker & Baepler, 2017).

Figure 3

Students show significant improvement in efficacy as scientists when comparing pre- to post-survey results



Note. Shown are (A) their perceived experience in designing a lab independently ($p < 0.001$; $n = 201$), (B) their comfort in explaining their thought process to their classmates ($p < 0.001$; $n = 222$), and (C) their perceived experience in analyzing data ($p < 0.001$; $n = 219$).

We administered the survey to students (n = 351) during the 2020-21 and 2021-22 academic years in the first (pre) and final (post) weeks of the semester. Our final data set only included student-course combinations for which we have matched pre- and post-survey data (n = 222). We intersected the survey data with grade and demographic data collated from university databases. Survey design and data collection were approved by our university's Institutional Review Board.

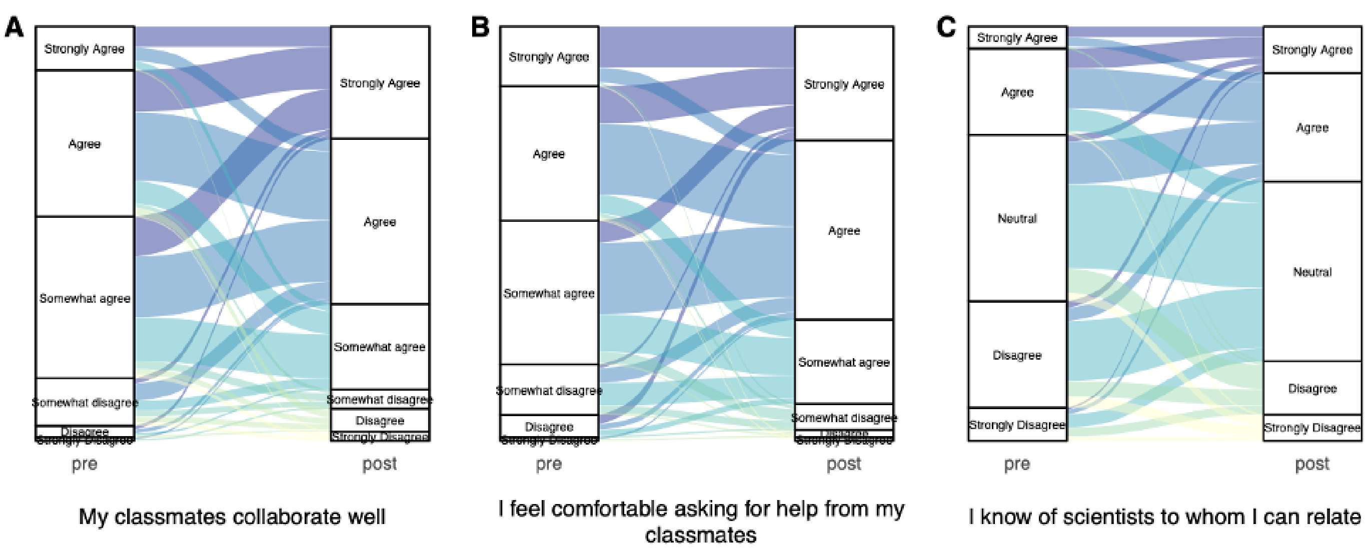
Statistical Analysis

Our evaluation of project efficacy was informed by our three project goals: increase student efficacy in their scientific abilities, increase student sense of belonging in the major, and increase student retention in the major. First, to evaluate if we increased student efficacy as scientists, we compared pre- and post-survey responses on questions related to students' comfort with the scientific method, quantitative skills, and scientific communication. We used sign tests to assess the significance of changes in student opinion, comparing our observed value to a null, non-parametric distribution generated using randomized bootstraps. We additionally tested for equity gaps in the post-survey responses by using a proportional odds ratio regression to determine if demographic categories were significant predictors of student responses. Second, to evaluate if we increased student sense of belonging (as measured by the social context scale), we again used sign tests and proportional odds ratio regression to compare pre- and post-survey responses on questions related to students' sense of community, comfort with teamwork, and feelings of inclusion in the broader scientific community. Finally, although our project aimed to increase student retention in the major, we cannot yet evaluate this project aim because most of the students in our dataset have yet to graduate.

In addition to evaluating our project goals, we determined if there were any equity gaps in

Figure 4

Students show significant improvement in sense of belonging when comparing pre- to post-survey results



Note. Shown is (A) their sense of how well they collaborate with their peers ($p < 0.001$; n = 218), (B) their comfort in asking their peers for help ($p < 0.001$; n = 222), and (C) whether they know of a scientist with whom they identify ($p < 0.001$; n = 187).

lab grades (as measured by grade point values) across sex[1], race, first-generation status, and transfer status. To do so, we fit a full linear model including all demographic factors and all constituent simpler models (glmulti v1.0.8; Calcagno & de Mazancourt, 2010). We evaluated model fit using Akaike Information Criteria (AIC). We also determined if student outcomes varied across CUREs versus non-CUREs, as CUREs typically introduce students to a wider range of scientific skills (Fig. 1) and are often considered the gold standard of IBEs. To do so, we compared the proportion of students agreeing or strongly agreeing with a statement in the post-survey, using randomized bootstraps to evaluate significance.

We conducted all analysis and figure generation in R v4.4.1 using packages tidyr, dplyr, and ggplot2; code is available at https://github.com/singhal/CELL-ms.

Results

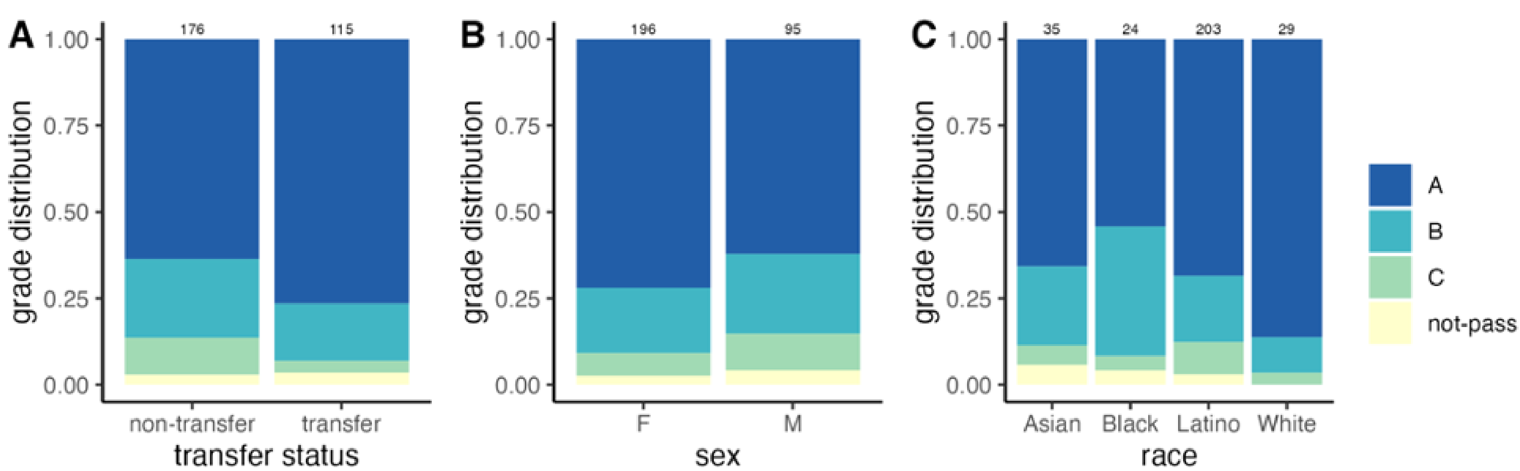
Redesigned Courses

Faculty redesigned their courses allowing for different levels of student autonomy and ownership (Hanauer et al., 2012; Weaver et al., 2008), based on a number of factors (Fig. 1). First, many of our students matriculate to our university from under-resourced high schools, where they were not exposed to hands-on labs (see also Spell et al., 2014). For these students, labs with greater structure are more appropriate for their developmental stage as scientists. Second, providing students more autonomy requires greater faculty effort (Shortlidge et al., 2016). At our institution, lower-division lab courses are often taught by graduate students or adjunct faculty, and the faculty roster changes regularly. In such cases, more guided labs—which typically require less investment of the faculty member—might be more

[1] Note: more detailed descriptions of the Methods and Findings are included in the Appendix.

Figure 5

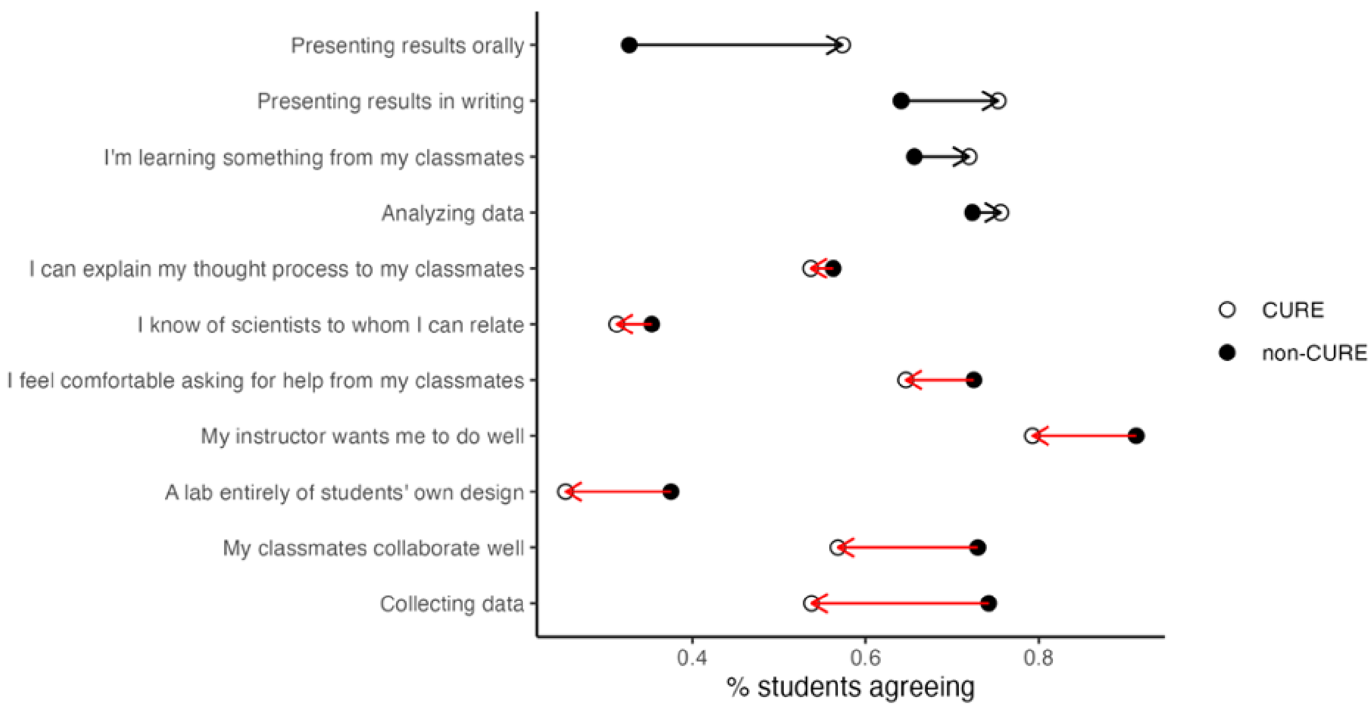
Student grades in redesigned lab courses



Note. Shown is 343 grades across 283 students; sample sizes are noted above each group. Grades are (A) higher for transfer versus non-transfer students, (B) females versus males, and (C) white versus non-white students; however, only the difference among transfer status is significant (adjusted r2 = 0.013; p-value = 0.02).

Figure 6

Difference in student outcomes among students enrolled in a lab redesigned as a course-based undergraduate research experience (CURE) versus a guided or open inquiry lab (non-CURE)



Note. Shown are the percentage of students agreeing with the following statement at the end of the course. Arrows reflect the gap in agreement between students enrolled in CUREs versus non-CUREs; red arrows indicate greater agreement in a non-CURE than a CURE.

manageable for the instructor (DeChenne-Peters & Scheuermann, 2022). Third, some courses have content requirements that they must satisfy, which might limit an instructor's flexibility to fully convert a course to full student ownership (Rissing & Cogan, 2009). For example, courses focused on biodiversity need to expose students to a diversity of life forms, irrespective of the focused question students are pursuing. Fourth, our faculty found our traditional labs could be converted into guided or open inquiry labs with relatively minor modifications to the lab design and lab materials (Kram & Eslami, n.d.), whereas conversion to fully autonomous labs often required more significant revision. Thus, conversion to guided or open inquiry labs required fewer resources and was easier to implement for our lab support staff. In Appendix 3, we illustrate the diversity of redesigned classes by highlighting a few courses.

Project Evaluation

First, we determined if our redesigned labs increased student efficacy as scientists by measuring student confidence with the scientific method, communication, and quantitative skills (Fig. 3; Table 1). More than 50% of students reported increased comfort with labs in which they have some or full input and/or labs with uncertain outcomes ($n = 201$; $p < 0.001$). While students showed significant increases

in confidence with reading the primary literature and collecting data, these gains were more modest (~30% of students report increased confidence; $n = 218$; $p < 0.001$). Students also grew more comfortable presenting their work informally to their peers and formally through oral and writing formats (50%, 34%, and 40% of students report increased confidence, respectively; $n = 216$; $p < 0.001$). Finally, 37% of students ($n = 219$; $p < 0.001$) reported increased comfort in analyzing data.

Second, we determined if our redesigned labs increased students' social context by measuring their comfort with teamwork, their sense of community, and their feelings of inclusion (Fig. 4). Forty-five percent of students ($n = 222$; $p < 0.001$) reported increased enjoyment learning from their peers and increased agreement that their classmates collaborate well. Through these redesigned labs, students also developed a stronger sense of belonging with their peers,—i.e., 48% have increased comfort asking their classmates for help ($n = 222$; $p < 0.001$)—and their instructor—i.e., 40% have increased belief that their instructor cares about them ($n = 221$; $p < 0.001$). Finally, by the end of the semester, 58% ($n = 187$; $p < 0.001$) of students increased their agreement with the statement: "I know of one or more important scientists to whom I relate." Despite this improvement, however, only 34% of students agreed or strongly agreed with this statement (Table 1). Across both analyses of student scientific efficacy and student belonging, we found no evidence for differential outcomes across demographic groups.

Then, we determined if there were equity gaps in the student grades in our redesigned labs. Overall, grades were high, and the not-passing rate was 3% ($n = 343$ grades across 283 students). These high grades fit historical trends in our major; lab courses typically boast high grades, and average grades in lab courses are often one to two grade points higher than the corresponding lecture classes. When we tested which demographic factors could predict the grade distributions, our best fitting model only included transfer status (adjusted $r2 = 0.013$; p-value = 0.02; Fig. 5).

Finally, we found that courses designed as CUREs and non-CUREs both positively impacted student outcomes, although the strength of their impact varied by metric (Fig. 6). For example, while students in CUREs show greater comfort with written and oral communication, students in non-CUREs show greater comfort collecting data and collaborating with classmates.

Discussion

Our project redesigned ten lower-division and upper-division lab courses as IBEs. Our initial project evaluation found that we made progress on our project goals of increasing student efficacy in their scientific abilities and student sense of belonging in the major (Fig. 3, 4; Table 1). Although we find evidence of equity gaps across demographic groups, none of these gaps are statistically significant (Fig. 5). Below, we discuss more general areas of strength and growth for our project, as well as limitations of our current study. Areas of strength

Our redesign had many areas of strength, some of which could not be fully captured by our quantitative data. For example, we learned that students were eager to engage in real science. We have many anecdotes of students excitingly discussing their experiments and results with each other (DeChenne-Peters & Scheuermann, 2022). Similarly, despite the chal-

Table 1

Student confidence across our project learning objectives (LOs) and project outcomes

LO / outcome	Survey statement	% of students agreeing	% change
Belonging	My instructor wants me to do well	87.2	32.8
	The students sitting near me respect my opinions	79.7	44.3
Communication	Presenting results in writing	67.9	33.7
	I can explain my thought process to my classmates	55.4	49.5
Inclusion	I know of scientists to whom I can relate	33.9	57.7
Quantitative	Analyzing data	73.4	37.4
Scientific method	Collecting data	67.4	31.7
	A lab in which students have some input	60.8	58.2
	Reading primary literature	49.4	28.9
Teamwork	My classmates collaborate well	67.5	45.4

Note. Shown are 10 survey statements reflective of general patterns. Percent change indicates the percentage of students who more strongly agree with the statement in the post- versus pre-survey.

lenges of designing an IBE, faculty also reported having more fun in these redesigned classes and feeling more engaged in collaboration with students (DeChenne-Peters & Scheuermann, 2022; Shortlidge et al., 2016). Not only were these labs more enjoyable, they are also more cost-effective. Previously, most labs staged a unique activity every week; now, students engage in a single topic over multiple weeks, some of which are dedicated to data analysis and writing. Because of these changes, these redesigned labs require fewer supplies and materials and are thus both cheaper and easier to manage for our lab staff.

From the start of the project, we aimed to provide faculty flexibility in how they redesigned their courses because courses have curricular restraints and faculty have their own pedagogical preferences. In addition, we wanted to provide faculty grace during the challenges of the COVID-19 pandemic. Because of this flexibility, our redesigned labs vary in their structure (Fig. 1), and some redesigned courses incorporate more aspects of the inquiry process than others. Despite this variance, our scaffolding helped ensure students were prepared to succeed in each course (McDonald et al., 2019; Spell et al., 2014). Further, we do not yet know what aspects of IBEs make them effective (Beck et al., 2023; Cooper et al., 2020), thus constraining instructor flexibility would not necessarily lead to improved outcomes. Ultimately, providing instructional flexibility allowed us to achieve many of our desired outcomes while also ensuring instructor freedom, and it might partially explain why we found both CUREs and non-CUREs were effective at improving student outcomes (Fig. 6).

Our project was also comprehensive. Because of the broad scope of the grant, we could involve almost all of our full-time faculty, and we were able to redesign 10 of the 18 laboratory classes in our curriculum. We were able to set collaborative goals as faculty and then intentionally scaffold the student experience across our courses to meet these goals. Because students are engaging in IBEs across the curriculum and across their academic development, this redesign should markedly impact the student experience.

Finally, we note that most previous explorations of IBEs have focused on implementations at relatively well-resourced institutions (but see McDonald et al., 2019). CSUDH is a relatively under-resourced university serving a high-need student body. We designed this project to be sustainable within our institutional context. For example, faculty at our institution teach relatively high-course loads (12 teaching units a semester, or the equivalent of four lecture courses), so faculty redesigned courses considering their limited out-of-classroom time for assessment and lab management. Further, our scaffolding allows students to develop along with their courses, and, because we are a commuter campus, faculty allocated course time for collaborative work to minimize scheduling challenges. Finally, students are charged relatively low lab fees, and none of these lab redesigns will increase these fees—in fact, this redesign might ultimately reduce lab fees. While this project was catalyzed by a generous grant, the structure and implementation of the project was designed to reflect our level of institutional resources. We hope our project thus shows that the benefits of IBEs can be accessible to all institutions.

Areas of growth

While this project had many strengths, we see areas of potential growth moving forward. First, our project needs to ensure that we are serving all our students. Our grade data identified equity gaps across demographic groups (Fig. 5); although statistically non-significant, this might simply reflect our small sample size. Moving forward, we will monitor and address equity gaps in these classes if they arise.

Second, conversion to IBEs was non-trivial for faculty. Participating faculty reported needing more professional development, particularly in how to convert current labs into IBEs. Because the official redesign period is over, we can no longer address this issue. However, we will work to ensure future curricular projects begin from a foundation of pedagogical training. Third, although faculty were largely positive about these labs, they reported a number of challenges, including that these redesigned labs were more time-consuming, required more impromptu thinking, and often had challenging logistics. These challenges are not unique to our redesign (Spell et al., 2014), and we are brainstorming how to manage faculty workload in the future—e.g., moving to one-page lab reports (Simmons et al., 2014). Alternatively, a strong central lab staff (Bakshi et al., 2016; Shapiro et al., 2015) or participation in a course research network (Auchincloss et al., 2014) can help mitigate some of these challenges.

Finally, our redesigned labs did not introduce students to all aspects of the scientific process (Fig. 1). As of yet, students are not publishing their results in peer-reviewed journals as has been seen in other CUREs (Auchincloss et al., 2014; Bangera & Brownell, 2014; Shortlidge et al., 2016). Further, while some redesigns have students iterate by building on previous datasets (Buchanan & Fisher, 2022), we do not—as yet—have students build on other student results. Some faculty are considering incorporating both of these elements to our upper-division IBEs.

Limitations of current study

This project suggests the promising ability of IBEs to improve student outcomes, including scientific self-efficacy and sense of belongingness. Yet, this study has some limitations. First, except for data from two courses, these study data were collected from fully online lab courses held during the COVID-19 pandemic. COVID-19 had a marked impact on the student experience, and not all students were affected equally (Barber et al., 2021). While we suspect that these lab redesigns will be even more efficacious in an in-person environment, this assumption remains untested. Second, although students will engage in multiple IBEs throughout their academic careers, we do not yet have the longitudinal data to evaluate the possible positive, cumulative effects of this scaffolding. Third, while most upper-division courses will be taught by the faculty who redesigned them, most lower-division courses will be taught by a diversity of instructors. Different instructors can elicit different outcomes with the same redesigned lab curriculum (Goodwin et al., 2022), so we will need to evaluate how robust our redesigns are to instructor variance. Finally, our data are both student self-reported and unpaired (Shortlidge & Brownell, 2016)—i.e., we do not have comparable data for our previous “cookbook” labs. Thus, while we are showing improved outcomes, “cookbook labs” could possibly result in similar outcomes.

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Appendix 1

The scaffolding of key learning objectives across the biology laboratory curriculum. Course titles as shown in Figure 1.

Course	Scientific Citation	Scientific Literature	Lab Reports	Figures & Tables	Lab Presentation	Teamwork	Statistics	Hypothesis generation
Introduction to Cellular & Molecular Biology	Parts of a citation	Primary versus secondary and trustworthiness	Writing figure legend; Writing methods	Identify dependent & independent variable; Make box plot and/or line graph	What should a presentation contain?		t-test	Difference between question and hypothesis; hypothesis should have a direction
Introduction to Biodiversity	Create a literature-cited page in proper CSE format	Finding scholarly sources, reading scientific literature, and evaluating the quality of various types of literature	What is plagiarism and how to avoid it; paraphrasing	Make a histogram; understand why/how bar graphs can be misleading; be able to explain relationships among variables	Presentation skills; focus on the skeleton of solid presentations	Goal setting for individual and group norms & expectations at start of term; end of term reflection of teamwork	Descriptive stats; t-test; chi-square	Difference between statistical and biological hypotheses; difference between hypotheses and predictions
Introduction to Ecology & Evolution	How to use a citation manager (Zotero)	How to break down figures	Writing introduction	Make a table	What does an effective slide look like?	How to use collaborative tools to help facilitate group work	Correlational statistics	Null versus alternate hypotheses
Molecular Biology	Find a relevant paper and cite it	Describe a figure from a paper to the class	Create a report with embedded figures and reference them	Writing effective legends	Describe a figure from a paper to the class			
Upper-division biology courses	Use multiple primary sources for a report and cite them	Describe multiple figures from a paper to the class	Deeper focus on scientific language	Multi-panel figure	Full-story presentation			

Appendix 2

The survey instrument used to evaluate student experiences in the redesign.

Pre-survey and Post-survey

Give an estimate of your current level of experience for (options: None, Some, Extensive, NA):

- **A scripted lab or project in which the students know the expected outcome.**
- **A lab or project in which only the instructor knows the outcome.**
- **A lab or project where no one knows the outcome.**
- **At least one project that is assigned and structured by the instructor.**
- **A project in which the students have some input into the research process and/or what is being studied.**
- **A project entirely of student's own design.**
- **Work individually.**
- **Work together as a whole class.**
- **Work in small groups.**
- **Become responsible for a part of the project.**
- **Read primary literature.**
- **Write a research proposal.**
- **Collect data.**
- **Analyze data.**
- **Present results orally.**
- **Present the results in written papers or reports.**
- **Present posters.**
- **Critique the work of other students.**
- **Listen to lectures.**
- **Read a textbook.**
- **Work on problem sets.**
- **Take tests in class.**
- **Discuss reading materials in class.**
- **Maintain lab notebooks.**
- **Computer modeling.**

For each statement below, indicate the extent to which you agree or disagree (Options: Strongly disagree, Disagree, Somewhat disagree, Somewhat agree, Agree, Strongly Agree).

- **For me, discussing materials in my biology course with my classmates is a waste of time.**
- **I would like to learn about topics discussed in my biology course from my peers.**
- **I've learning something from my classmate**
- **I can explain my ideas in specific terms**
- **The people sitting near me have learned something from me**
- **The instructor knows my name**
- **My instructor makes class enjoyable**
- **I can clearly explain new concepts I've learned to others in class**
- **The students sitting near me rely on each other for help in learning class material**

- **People sitting near me in class work well together on class assignments**
- **The instructor seems to care about me**
- **My instructor wants me to do well on the assignments in this class**
- **The instructor is acquainted with me.**
- **I can persuade my classmates why my ideas are relevant to the problems we encounter in class**
- **I know something personal about the people sitting near me**
- **I feel comfortable asking for help from classmates.**
- **I can use the terminology in this class correctly**
- **Sometimes I feel like my instructor and I are on opposing teams in this class**
- **I can explain my thought process from start to finish to others in class.**
- **I've spoken informally with the instructor before, during, or after class**
- **I am acquainted with the students sitting near me in class**
- **My instructor encourages questions and comments from students**
- **I can help others in this class learn**
- **The students sitting near me respect my opinions**
- **Other students pointed out a helpful resource**
- **Other students explained a concept to me**
- **I know of one or more important scientist to whom I can personally relate**

Based on what you know now, describe the types of people that do science. If possible, refer to specific scientists and what they tell you about the types of people that do science. (open ended)

Post-survey only

In this course, I was encouraged (options: Never, one or two times, monthly, weekly, I don't know)

- **To discuss elements of my investigation with classmates or instructors**
- **To reflect on what I was learning**
- **To contribute my ideas and suggestions during class discussions**
- **To help other students collect or analyze data**
- **To provide constructive criticism to classmates**

Appendix 3

Below, we highlight the diversity of redesigned courses by describing five of our ten redesigned classes.

Lower-Division Course: Introduction to Biodiversity

This lab was converted into four modules, three of which were open-ended inquiry modules that varied in length from one to four weeks. In one module, students collected, observed, and documented microbial diversity on campus. Through this module, students reviewed key course content on microbial diversity—i.e., what are the key characteristics of fungi versus protists, made predictions about biodiversity patterns, and developed skills in scientific written and oral communication like writing reports, illustrating biodiversity, and presenting their experimental procedures and results to the class. This module was only taught in-person.

Lower-Division Course: Introduction to Ecology & Evolution

This lab was converted into four three-week open-ended inquiry modules. In the first module, students explore how abiotic factors influence some aspect of brine shrimp biology. Students defined their own research question, hypothesis, and methods, collected and analyzed data, and wrote the Methods & Results sections of a lab report. Through this module, students learned how to make a boxplot and conduct a t-test, and some groups presented on this project in a formal scientific presentation at the semester-end research showcase.

In the online environment, the course instructor sent students mini-science kits containing all the basic materials to do this experiment at home.

Lower-Division Course: Molecular Biology

This lab was converted into two modules, one of which was a guided inquiry lab and the other of which is a CURE. For the CURE module, students participate in the Tiny Earth research project, in which students across the nation isolate local soil microbes to develop new antibiotics (Miller et al., 2023). Students developed research questions and hypotheses, practiced key technical skills like sterile technique and micropipetting, and learned how to analyze genetic sequencing data. Students found primary literature relevant to their bacterial isolates and then shared their findings in a group lab presentation. This module was only taught in-person.

Upper-Division Course: Ecology

This lab was converted into four CUREs, each of which ran for multiple weeks (Valliere, 2022a, 2022b). In one project, students investigated how anthropogenic disturbance affected the coyotes resident on CSUDH's campus (Valliere, 2022a). They analyzed camera trap data to determine coyote activity patterns and scat data to understand coyote diet. Through this project, students were trained in RStudio and wrote a formal lab report. This course's data are being used by the campus Risk Management office to develop appropriate plans for managing the campus urban coyote population.

In the online environment, the course instructor did the initial data collection and management of the coyote camera trap and scat data, which students then analyzed remotely.

Upper-Division Course: Microbiology

This lab was converted into a CURE module and a guided inquiry module. In the CURE module, students collect microbial samples from their cellphones, prepare DNA barcoding libraries, and then collect high-throughput sequencing data. Students used bioinformatic tools to determine the microbiome structure of their cellphones (Hall & Beiko, 2018; Hilgert et al., 2014), propose explanations for the patterns they see, and share their results in a formal lab report.

In the online environment, the course instructor followed the same approach, but students instead analyzed data collected from previous semesters of this class.

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