Effects of a Research-Based Ecology Lab Course: A Study of Nonvolunteer Achievement, Self-Confidence, and Perception of Lab Course Purpose

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Undergraduate biology lab courses have long been criticized for engaging students in "cookbook" experiences in which students follow a given protocol to collect data that help answer a predetermined question. Recent reform documents in biology education have suggested that students should engage in lab courses that provide more authentic research experiences in which students are responsible for the development of research questions, the collection of data, and its analysis. This paper presents the evaluation of a research-based introductory biology lab course focused on an ecological system. Pre- and postcourse surveys and performance assessments were administered to nonvolunteer students to measure the course's impact on cognitive and affective constructs. Results indicate that participation in the authentic lab course improved students' experimental design and data interpretation abilities at a statistically significant level. Furthermore, students' confidence in their ability to execute authentic lab tasks as well as their perception of the lab's purpose changed over time, both in ways that reflect more authentic engagement in scientific research.

Undergraduate biology education has the challenging task of preparing students for a 21st-century context that has experienced rapid technological changes and movements toward interdisciplinary work. Several national reports, including *Bio2010* (National Research Council, 2003), *The New Biology Curriculum* (National Research Council, 2009), and *Vision and Change* (American Association for the Advancement of Science, 2011), have outlined principles necessary for biology education to meet this goal. One major tenet of these reports is to engage undergraduate students in authentic research in the form of research assistantships in individual faculty members' labs (Boyd & Wesemann, 2009; Taraban & Blanton, 2008) and research-based lab courses (Sundberg, Armstrong, & Wischusen, 2005; Weaver, Russell, & Wink, 2008; Wood, 2003).

Research assistantships have been shown to enhance attitudes of undergraduates toward biological research (Boyd & Wesemann, 2009; Lopatto, 2007; Taraban & Blanton, 2008), but most colleges and universities do not have the capacity to provide research opportunities for all undergraduate biology or premedical students. For students who do not have an opportunity to participate in faculty research, the required sequence of lab courses is often their only exposure to scientific practices. Unfortunately, most of these courses are taught in a "cookbook" manner, in which students follow a protocol, like a recipe, with a known answer (Buck, Bretz, & Towns, 2008; Sundberg et al., 2005). However, providing high-quality biology education to all students is important for training the next generation of both scientists and scientifically literate citizens.

In response to criticisms of cookbook labs, several institutions have designed courses that better reflect authentic research in which students "develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (National Research Council, 2000, p. 1). However, few research-based courses have been evaluated beyond traditional course evaluation methods (Henderson, Beach, & Finkelstein, 2011). For example, many lab courses that have been evaluated lack a pre/postcourse assessment structure to show learning or affect gains (Casem, 2006; Halme, Khodor, Mitchell, & Walker, 2006; Myka & Raubenheimer, 2005; Rutledge, Mathis, & Seipelt, 2004; Seifert, Fenster, Dilts, & Temple, 2009). Some pioneering studies have compared students taking research-based lab courses with those taking more traditional cookbook-style courses (Brownell, Kloser, Fukami, & Shavelson, 2012; Burrowes & Nazario, 2008; Rissing & Cogan, 2009; Russell & French, 2002; Shaffer et al., 2010), but these studies often use volunteer students for the two conditions. Comparisons between volunteers may overestimate the value of research-based courses because of unsystematic differences between the two groups at the outset of the study and the self-selection of a research-based course. A small number of studies have used a randomized design, but these studies, although valuable, often rely only on student self-reports to gauge the success of the course (Brickman, Gormally, Armstrong, & Hallar, 2009; Simmons, Wu, Knight, & Lopez, 2008). To improve research-based courses, evaluations are needed that measure the achievement of nonvolunteers that are assigned to this type of course.

In this paper, we describe the content, structure, and evaluation of a recently designed and executed research-based introductory biology lab course that was taken by students who were nonvolunteers. This study is a modified replication of a previous study published in the *Journal of College Science Teaching* (Brownell et al., 2012), with three important differences. First, instead of volunteers, this evaluation uses nonvolunteers who were randomly assigned to this course. Second, this study uses a slightly larger sample size. Third, this study includes a performance assessment component in addition to student self-report data.

The course is intended to serve a student population with minimal previous biology lab training. We present data on the effect of the course on students' cognitive and affective outcomes. We propose that the overall course structure outlined here could be adapted to fit diverse environments at many research-intensive universities.

Course content and structure

Course goals

This introductory undergraduate course was designed to engage students in authentic research experiences rooted in the current research of the instructor (fourth author of this article). Thus, the resulting lab course straddles the line between teaching and research (Kloser, Brownell, Chiariello, & Fukami, 2011). In designing the course, the instructional team identified hallmarks of scientific thinking and skills that reflect authentic research practices, as defined by documents such as *Bio2010* (National Research Council, 2003) and *Vision and Change* (American Association for the Advancement of Science, 2011). These include an emphasis on student collaboration; the use of modern techniques to study longitudinal, opened-ended research questions with unknown answers; and scientific communication of results (Figure 1).

FIGURE 1

Goals for research-based lab course.

1. Students will conduct guided inquiry on open-ended questions that reflect biological research practice in the context of ecology.
2. Students will analyze data and propose justifiable conclusions.
3. Students will conduct elements of scientific research both independently and collaboratively.
4. Labs will stimulate student interest in future biological research and encourage participation in research endeavors.
5. Students will develop critical thinking skills in biological research that are transferable to other research experiences.
6. Students will experience the successes and failures of lab research.
7. Students will experience the successes and challenges of collaborative research.
8. Students will communicate results in a discipline-appropriate manner through various media.

Course content

Students focused on ecological relationships between a set of biotic and abiotic factors. Biotic factors included the sticky monkeyflower (*Mimulus aurantiacus*), a common shrub that is native to California; the hummingbirds and insects that pollinate the plant; and the yeast communities that assemble in the floral nectar of the plant. Abiotic factors included light, temperature, and water. Students used this system as a basis for generating and testing hypotheses on ecological interactions (Figure 2).

Mimulus aurantiacus is a model system for studying interactions that shape yeast community assembly in floral nectar. This plant occupies habitats that differ substantially in thermal and light environments, which can be monitored at the level of the individual plant (Belisle, Peay, & Fukami, 2012). This variation allowed students to postulate a range of testable hypotheses about the effects of local variation in light, temperature, and hydration on a network of biotic interactions that ultimately shape the community of yeast in nectar. Additionally, this system is the focus of the instructor's research program, allowing him to bring research expertise to the course (Peay, Belisle, & Fukami, 2012; Vannette, Gauthier, & Fukami, in press).

Course structure

This introductory undergraduate biology lab course is the second lab course in a two-course sequence intended for students concurrently enrolled in an introductory biology lecture course. The majority of students enrolled in this course have previously taken two biology lecture courses and one biology lab course. During the 10-week quarter, students were introduced to the study system and hypothesis-testing methods. Each team of two students chose an abiotic factor (e.g., light, temperature, or water) and a biotic factor (e.g., flowering phenology, pollinator visits, or butterfly larvae abundance). On the basis of existing literature and course material, each team formulated two to three hypotheses regarding relationships between nectar-living yeasts and two factors of their choice. Students collected data and uploaded it to a large database that hosted data collected by all of the students in the class during the quarter and other data that had been collected previously by the instructor and other students. Students selected which data to sample and the appropriate data analyses to test their respective hypotheses. Students presented their results in the form of a conference-like oral presentation and in a written scientific paper.

Course organization

The professor of the course held a 1-hour lecture associated with the lab every week during which he introduced the ecological system, statistical techniques, and step-by-step modeling of writing sections of a scientific paper. Each of these lectures used primary literature as the main source of discussion. Having this discussion section at a different time from the lab section provided students time for discussion and analysis without the pressures of completing a lab protocol.

Each week, students also attended a lab session that was 4 hours in length. These were mostly held at a nearby research field station or in the campus biology labs. Sessions at the research field station incorporated a range of tasks. For the first hour, lab partners collected data on a given set of eight *Mimulus* plants. Students charted the number of caterpillars, new buds, and flowers each week. These data were then uploaded to a common database that was accessible to all students. Students were also given demonstrations of different ecology research instruments used to collect some of the data.

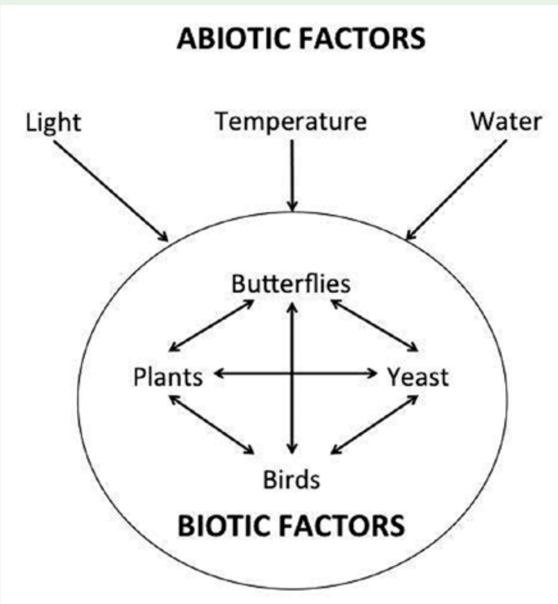
Students engaged in aspects of authentic research such as developing research questions and hypotheses. For example, as shown in this excerpt from a student's paper, one student group tested the following hypotheses:

> This paper hypothesizes that daily temperature has a significant effect on the prevalence of yeast colonizing *Mimulus aurantiacus* . . . In addition to its direct effects, temperature is hypothesized to influence yeast prevalence through a pathway of biotic factors . . . Increasing temperature is expected to be linearly correlated with increasing number of flowers, which is then expected to show a linear relationship with increased number of pollinator visits. More pollinator visits, in turn, is [sic] expected to lead to increased number of yeast colonizing a plant's flowers.

Other tasks focused on students recording and analyzing data. This ranged from culturing yeast to downloading the temperature data from

FIGURE 2

Abiotic and biotic experimental variables used in students' investigations.



iButton probes that record a localized temperature every 10 minutes. Students decided which of the statistical techniques was most appropriate to test their hypotheses.

Assignments

Students were required to do prelab and postlab assignments focused on scientific content and data analysis, respectively. In place of a preprinted lab manual, resource materials were posted electronically on the course website, and students maintained a hardbound laboratory notebook, similar to what they would use to record data in an authentic research lab. Students synthesized multiple drafts of a lab report based on their data that included the traditional sections of a scientific paper following the format specified by the journal *Ecology*. Teaching assistants provided feedback to supplement the comments generated by peer review. Students also presented their projects orally to peers and the instructional team, followed by 5 minutes for Q&A.

Course instructional team

A tenure-track assistant professor taught all of the Monday lectures and attended most of the weekly lab sessions. A lab coordinator handled all course logistics and was present during all of the lab sessions. There was also one graduate student teaching assistant per lab session.

Course evaluation methods

Evaluation instruments

External assessment of students was conducted using surveys and a performance assessment measure of achievement. Student surveys were administered on the first and last days of the course. The precourse survey included an open-ended response format question that probed students' views of the lab's purpose. Furthermore, the survey included three blocks of Likert-type scale survey questions on the following domains: student self-confidence in executing lab tasks, student interest in biological research, and student preferences for biology lab courses. The precourse survey also included questions on student demographics (see Appendix 1, available online at http://www.nsta.org/college/connections.aspx).

The postcourse survey included the same question probing students' perceptions of the lab's purpose as well as the three blocks of Likert-style survey questions asked on the precourse survey (Appendix 1).

The performance assessment also included a pre- and postcourse format. The precourse assessment (see Appendix 2, available online at http://www.nsta.org/college/connections.aspx) included a mix of multiple-choice and free-response questions focused on two subtopics—experimental design and data interpretation—that were different from the specific focus of the lab. For the experimental design section, students were given a one-page description of a research problem involving various-sized pieces of land fragmented by volcanic activity and the biotic interactions that occurred in these fragments. After reading the background information and the given research questions, students were asked to design their own experiment that would address the research question. As part of their response, students were asked to include the following information: (a) general description of the methods used, (b) sampling, and (c) controls.

Although these instructions primed students to include certain factors in their answer, they limited student ambiguity about what should be included in the response and, in turn, allowed for more consistent scoring. Students were given a blank answer sheet on which to provide their response.

For the data interpretation subsection, students were given an ecological system that posited suspected relationships between biotic organisms. Students were also given a set of six figures that provided empirical evidence for these relationships. Some of the figures showed statistically significant results, whereas others showed insignificant results or minimal data points necessary for valid interpretation. Students were asked a series of six multiple-choice questions in which they had to interpret the figures in light of the ecological system. A final free-response question asked students to write a brief paragraph justifying whether the data support or do not support the original research hypotheses.

On the final day of the course, students took an isomorphic postcourse assessment (see Appendix 3, available online at http://www.nsta.org/college/connections.aspx). The organisms and ecological web were changed for the posttest to prevent students from remembering their responses from the pretest, but question structure remained the same. Furthermore, the figures of data were rearranged and the p-values changed but required the same interpretation skills as the pretest. Notably, course instructors did not know the content of the performance assessments; they did not develop, administer, or score the assessments, which prevented the possibility of them teaching to the test. Also, these were not part of students' grades in the course. It is possible that because assessments were not part of the course grade, student motivation to fully engage in the task might have been affected. Although two students' assessments were eliminated from the study because they left more than half of the questions blank, the majority of students completely answered all of the pre- and postcourse questions.

Participant sample

Participants in this study were part of a larger cohort of students registered to take the introductory biology lab course at Stanford University, a private research-intensive university. Students were randomly assigned to this lab course. This population of nonvolunteer students was important because studies have suggested that a self-selection bias could affect student motivation, interest, and dedication (Rosenthal, 1965).

Table 1 shows the demographic breakdown of the 33 students that participated in the research-based course. (Two students are not shown because they did not complete the pre- or postcourse surveys or assessments.) This group of students was divided among four different lab groups with a maximum of 10 students and a minimum of 6 students per day.

Scoring and data analysis

Pre/postcourse surveys

Likert-type survey questions were analyzed using paired sample (pre/post) *t*-tests in SPSS ($\alpha = .05$). The survey also contained one open-ended question that was coded by two separate raters, blind to the pre/post nature of the data. On the basis of pilot data from the previous year, student responses to the question about the lab's purpose were coded into four categories: (1) learning lab techniques, (2) developing competency in research/experimental design, (3) learning how to analyze and interpret data, and (4) other miscellaneous responses (see Appendix 4, available online at http://www.nsta.org/college/connections.aspx, for full description and example responses). Interrater agreement between the two coders for this question exceeded 0.80 on the first round of coding. Coding disagreements were discussed by the two raters until a consensus code was agreed on.

Performance assessment

Free-response questions (Part I, Part II #7) from the pre/postcourse performance assessment were coded on the basis of a rubric developed by the authors on the basis of pilot responses by graduate students in biology (Appendix 4 contains codes, descriptions, and examples for all free-response codes).

Two raters, both doctoral students in biology, blind to the pre/post nature of each test, were trained on the rubric using a sample of authentic responses from students who piloted the performance assessments. After an hour of training, the raters coded 16 of the 60 assessments; they reached perfect agreement on 75% of the assessments and differed by only 1 point on 100% of the assessments. Where differences occurred, consensus was reached between the raters about the proper score. At this point it was determined that the remaining assessments could be scored by one of the raters. Pre/postcourse assessments were analyzed for each subsection using paired *t*-tests in SPSS ($\alpha = .05$).

Course evaluation results

Perceptions of the lab's purpose

Results from the precourse survey indicated that students most frequently identified learning lab techniques or skills, such as pipetting or PCR, as the purpose of the lab (18 of 33 responses) prior to taking the course (Figure 3). A repeated measures analysis of variance (ANOVA) indicated statistically significant shifts in students' perceptions of the purpose of the lab from pre- to postcourse survey, $F(1, 32) = 17.71$, $p < .001$. Qualitatively, Figure 3 shows a distribution shift away from the learning lab techniques and skills category. Chi-squared tests for each set of responses indicated a statistically significant difference between students' pre- and postcourse perception of the lab's purpose with significantly fewer students indicating that learning lab techniques was the purpose of the lab in the postcourse survey, $\chi^2(1, 32) = 9.96$, $p = .001$. Figure 3 shows increased responses for each of the other three categories—research design, data analysis, and other—on the postcourse survey,

TABLE 1

Participant demographics.

		Gender		Class year			Self-reported GPA range			
	N	M	F	Soph.	Jr.	Sr.	<3.26	3.26–3.50	3.51–3.75	3.76–4.00
Participants	33	11	22	9	10	14	6	11	9	7

but chi-squared tests did not indicate a significant increase for any of these individual responses.

Lab effect on cognitive factors

Student achievement on the pre/posttassessment consisted of a total score and two subscores, experimental design and data interpretation. A randomized blocks ANOVA with two factors, occasion and subscale, were used to determine the difference in students' scores over time and on each of the subscales, respectively. The main effect for occasion showed that students' posttest overall scores (M = 11.45, SD = 2.26) were statistically higher when compared to pretest overall scores (M = 8.84, SD = 2.54), $F(1, 30) = 27.68$, $p < .0001$ (Figure 4).

The experimental design subscore increased significantly from pretest (M = 3.35, SD = 1.60) to posttest (M = 4.19, SD = 1.47), as did the data interpretation subscale pretest (M = 5.48, SD = 1.93) to posttest (M = 7.26, SD = 1.71). The main effect for subscale and the occasion × subscale interaction were not statistically significant at the .05 level, indicating that both subscales increased, on average, by the same amount from pretest to posttest.

Lab effect on noncognitive factors

Pre- and postcourse surveys measured student self-reports of noncognitive factors related to their lab experience. Results were grouped into three different constructs. The first construct focused on students' self-confidence in completing lab-based research tasks. Four of the six questions in this domain—developing a scientific question, developing a lab protocol, interpreting experimental data, and presenting lab results to lab members—showed statistically significant gains at the 0.05 level (Table 2), with

FIGURE 3

Coded student responses (n = 33) to the open-ended survey question: What is the primary purpose of this lab course? The omnibus test indicated an overall statistical difference between pre- and posttest results at $p < .05$. ** = $p < .001$ based on a chi-squared of pre/postcourse responses for each response choice.

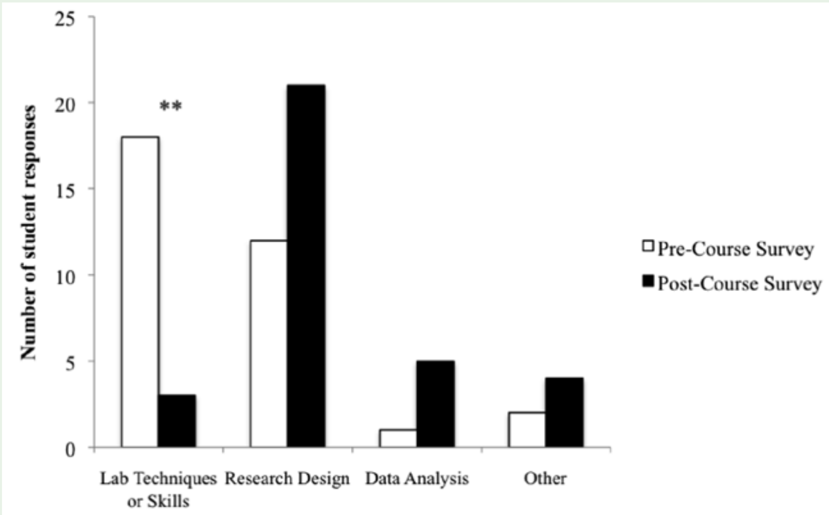
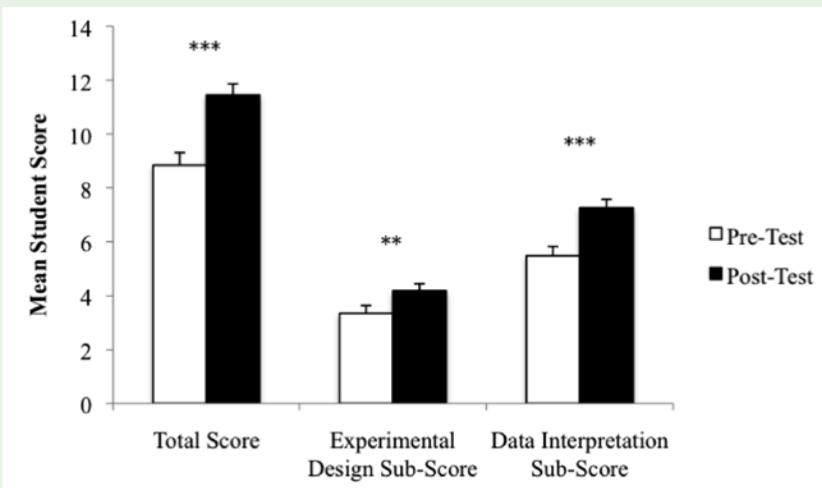


FIGURE 4

Performance assessment pre/post results (n = 33). Total possible points = 18. Tests were scored blindly by two independent raters who reached 80% agreement on 25% of the sample before scoring tests individually. Scores were analyzed using a randomized blocks ANOVA with two factors, occasion and subscale. Significant results for the main effect of occasions are shown followed by the disaggregated subscores for the experimental design and data interpretation portions of the assessment. ** = $p < .001$. *** = $p < .0001$.



large effect sizes, based on Cohen's *d*, for the first two questions, and medium effect sizes for the second two questions. Student scores for the final two questions—self-confidence in writing a full-length lab report and working as an undergraduate lab assistant—both increased, but not at statistically significant levels.

Questions measuring students' short- and long-term interest in pursuing biological research opportunities represented a second construct. For each of the four questions, students showed no statistically significant change in their levels of interest for pursuing an honors thesis, applying as an undergraduate lab assistant, doing biological research after graduation, or doing other scientific research after graduation (Table 3).

TABLE 2

Postcourse survey means, (*standard deviations*), and gain scores for the question: How confident do you feel in your ability to execute the following biology lab-based tasks?

	Precourse	Postcourse	Gain	Effect size
1. Develop my own scientific question.	3.24 (*0.902*)	4.12 (*0.740*)	0.879* (*1.02*)	1.07
2. Design my own experimental lab protocol.	2.79 (*0.893*)	3.76 (*0.792*)	0.970* (*1.13*)	1.15
3. Interpret experimental data.	3.33 (*0.957*)	3.97 (*0.637*)	0.636* (*0.929*)	0.79
4. Present lab results to my lab members.	3.73 (*0.944*)	4.15 (*0.667*)	0.424* (*0.867*)	0.51
5. Write an accurate full-length lab report (Intro, Methods, Results, Discussion).	3.64 (*0.929*)	3.82 (*0.683*)	0.182 (*0.683*)	—
6. Work as an undergraduate research lab assistant in a biology lab.	3.67 (*0.957*)	3.91 (*1.10*)	0.242 (*1.12*)	—

Note: n = 33. Scale = (1) *not confident*, (2) *somewhat confident*, (3) *moderately confident*, (4) *very confident*, (5) *extremely confident*. Cohen's effect sizes: small = .25, medium = .50, large = .80.

*Within group significance based on paired sample *t*-test ($p < .05$).

TABLE 3

Postcourse survey means, (*standard deviations*), and gain scores for the question: What is your level of interest for doing the following research-related experiences?

	Precourse	Postcourse	Gain	Effect size
1. Doing a biology honors thesis in experimental scientific research.	1.90 (*1.35*)	2.00 (*1.34*)	0.097 (*1.50*)	—
2. Applying for biology or other science-related undergraduate lab research positions.	2.39 (*1.54*)	2.10 (*1.62*)	–0.290 (*1.92*)	—
3. Doing biological research after graduation.	2.39 (*0.955*)	2.61 (*1.15*)	0.226 (*1.11*)	—
4. Doing nonbiological scientific research after graduation.	2.81 (*1.14*)	3.00 (*1.37*)	0.194 (*0.946*)	—

Note: n = 33. Scale = (1) *not at all interested,* (2) *somewhat interested,* (3) *moderately interested,* (4) *very interested,* (5) *extremely interested.* Cohen's effect sizes: small = .25, medium = .50, large = .80.

Within group significance based on paired sample *t*-test ($p < .05$).

The final domain of questions focused on students' preferences toward lab courses. Statistics from the positive form of the question in relation to authentic research are shown in Table 4. Negatively worded questions showed the same statistical trends. For three of the four questions, students showed statistically significant gains from pre- to postcourse survey in favor of more authentic lab courses. This included a stronger preference for lab courses that focused on longitudinal questions, allowed for student autonomy in decision making, and promoted collaboration (Table 4). Effect sizes for the significant findings ranged from small to medium.

Discussion

In this study, we explored the effect of this course experience on students' attitudes toward authentic research, interest in pursuing future research, and self-confidence in performing lab tasks. Additionally, we investigated the effect of a research-based course on student achievement in the context of an ecology lab course.

Evaluation results showed that students improved their ability to design an experiment and interpret data. These significant gains indicate the positive effect of the course on authentic research skills. Because this is an introductory lab course, engaging many students for the first time in designing experiments and interpreting data, we would not expect proficiency at the end of this course, but we do see the positive gains as evidence for incremental progress. Although we would predict assessment gains following an intervention, it was nevertheless important to develop an assessment independent from course-based tasks and unseen by course instructors to prevent students being primed for a specific assessment.

In terms of affect, students showed the strongest gains in their self-confidence to perform lab-based tasks such as posing research questions and interpreting data. This preference was also reflected on the gains of both subscores, experimental design, and interpreting data on the performance assessment. Furthermore, students' preferences for investigating open-ended longitudinal research questions, making decisions about their lab experience, and collaborating in the lab showed significant gains over the course of the class.

Initially, we were surprised that the students did not change in terms of the level of short- or long-term interest in doing scientific research, because previous data indicated significant increases in short-term interest to do an honors research thesis or work in an on-campus lab (Brownell et al., 2012). However, this previous set of data was taken from a group of volunteers, not students randomized into this course. These volunteer students were likely different from the larger population of students required to take the course. In contrast, the students in our current study had no choice in the lab course to which they were assigned. This difference in outcome data between the volunteer students and the randomly

TABLE 4

Postcourse survey means, (*standard deviations*), and gain scores for the question: What is your level of agreement with the following statements related to biology lab courses?

	Precourse	Postcourse	Gain	Effect size
1. I prefer lab courses that explore a set of research questions focused on a single continuous topic for the quarter	3.18 (*0.846*)	3.67 (*1.02*)	0.485* (*0.939*)	0.52
2. I prefer to make my own decisions about what experiments to do in lab courses	3.15 (*0.834*)	3.48 (*0.906*)	0.333* (*0.957*)	0.38
3. I prefer lab courses that explore an open-ended question for which the answer is not predetermined	3.45 (*0.833*)	3.58 (*0.751*)	0.121 (*0.857*)	—
4. I believe that collaboration is an important part of lab courses	4.18 (0.882)	4.45 (0.711)	0.485* (0.906)	0.34

Note: $n = 33$. The opposite form of each of the above questions (e.g., "I prefer lab courses in which the answer is already known" was asked, and scores are not reported here as they represented the statistically significant reciprocal trend. Scale = (1) *strongly disagree*, (2) *disagree*, (3) *do not agree or disagree*, (4) *agree*, (5) *strongly agree*. Cohen's effect sizes: small = .25, medium = .50, large = .80.

*Within group significance based on paired sample t-test ($p < .05$).

assigned students underscores the caution necessary when interpreting data from course evaluations in which students were not randomly assigned and emphasizes the need for more randomized experiments when addressing the effect of courses (Henderson et al., 2011).

Although the evaluation results are encouraging, several variables limit generalizations. As shown in the demographic data (Table 1), the pool of students included generally high-performing undergraduates. It is unclear from this data how motivations and achievement would be different for students with lower GPAs or students who enter college with lower standardized test scores. Furthermore, the size of the lab sections reported previously is smaller than lab sections in most research-focused universities, and thus the student-to-faculty ratio is also smaller than in many contexts. Anticipating the needs of much larger institutions, the following section raises questions for bringing this type of lab to scale.

Questions for replication and improvement

Creating research-based lab courses can be challenging, especially for large introductory courses that have diverse student populations. The type of course we evaluated benefits students by presenting them with a contemporary, authentic problem in which expertise and some research infrastructure already exists. However, this approach must overcome obstacles of scale. In principle, this type of lab course seems ideal for students, but in practice, it is not trivial to take the model of an independent research experience and expand it to meet the educational needs of a large number of students with diverse interests and motivations for taking the course. Whereas faculty labs select undergraduates from a pool of volunteers interested in their area of research, lab courses like the one described previously must cater to students required to enroll in the course, sometimes solely to fulfill a major or premedical requirement. Nevertheless, the results from this lab course evaluation provided evidence that executing a course focused on the hallmarks of authentic biological research led by an expert in the given system can positively impact student affect toward biological research and their performance on research-based tasks. This course will eventually be scaled up five-fold to approximately 150 students. It will be essential to evaluate the fully scaled-up course to see if the same benefits are achieved.

Conclusion

We have shown that, even with students assigned to the research-based lab course who may vary in their interest and motivation, authentic research experiences in a formal course setting can significantly affect students' understanding of experimental design and data interpretation skills as well as affective measures such as self-confidence in completing lab-based tasks. Continued research should focus on both affective and performance-based evaluations. We hope that the course and evaluation methods we have described in this article can serve as an example from which similar efforts can be developed elsewhere. ■

Note: The first two authors contributed equally to the work.

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