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Method for Integrating Components of a CURE into an Introductory Biology Traditional Laboratory†

Jamie L. Brusa[1]* and Randi C. Lupardus[2]
[1]*Department of Ecology, Montana State University, Bozeman, MT 59717, USA;*
[2]*Department of Renewable Resources, University of Alberta, Edmonton, AB T6G 2R3, Canada*

INTRODUCTION

Undergraduate biology instructors face the challenge of balancing critical thinking procedures with biology content (1). Evidence has revealed that directed "cookbook" laboratory exercises alone severely limit opportunities to interpret data and practice higher-order thinking (2, 3). However, concurrently learning complex biological concepts and practicing higher-order thinking, such as inquiry laboratory activities, is thought to enhance comprehension of biological concepts (4, 5). Course-based undergraduate research experiences, or CUREs, have become a popular method of instruction because they provide access to research experience for all students (6–8). However, financial barriers, increased time investment, lack of institutional support, and the narrow scope of topics and laboratory skills gained in CUREs relative to traditional laboratory activities can present challenges for laboratory instructors who desire to provide a robust curriculum (5, 9). Ideally, laboratory curricula include learning outcomes for students to gain a diversity of laboratory skills, reinforce biology concepts, practice higher-order thinking, and develop an understanding of the research process.

Given the vast amount of information covered in introductory biology courses, students might benefit from a laboratory component that focuses, at least partly, on reinforcing complex concepts discussed in the lecture component. In research-based laboratories, students might struggle to make connections between theoretical concepts discussed in lecture and research experiences in laboratory sessions if the research topic is too narrow. For laboratories that afford time for students to engage in CURE-related activities and supplemental instruction to reinforce lecture topics, a CURE can provide students with research experience without sacrificing the connection between lecture and laboratory (10). However, these supplemental instruction sessions tend to include worksheets rather than laboratory methods.

Here, we describe the framework to update a one-semester introductory cellular and molecular biology laboratory curriculum to employ techniques of both traditional laboratories and CUREs. The primary goals of this framework are to provide students with opportunities to practice conducting a semester-long research project and engage in a laboratory that includes nearly all characteristics of a CURE (6) without the potential tradeoff of losing an opportunity to practice reinforcing concepts learned in the lecture portion of the course. Our framework can increase student engagement by providing students ample freedom to design experiments directly related to their interests. Our framework also leads students to connect current course topics (e.g., photosynthesis, cell respiration) to their research projects. We present insight gained from student answers to a questionnaire regarding their perceptions of incorporating a semester-long research project into a traditional laboratory curriculum.

PROCEDURE

The integration of a semester-long research project as described below is appropriate for an introductory college biology course with weekly themed laboratory experiments (e.g., osmosis, enzymes) that emphasize guided inquiry and open-ended investigations. Appendix 1 describes the learning objectives. Students chose one of three general frameworks provided for their semester-long research project: an experimental or observational study using soil seedbanks, an experimental study using green onions in a highly controlled setting, or an observational study of a phenological event (Appendices 2 and 3). These frameworks provide guidance to students while enabling them to conduct a research project related to their interests and career goals. Students with more advanced research backgrounds had the freedom to design research projects with more complexity, but students with little or no prior

*Corresponding author. Mailing address: Department of Ecology, Montana State University, 310 Lewis Hall, P.O. Box 173460, Bozeman, MT 59717. Phone: 847-767-7761. E-mail: jlbwcc@gmail.com.
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TABLE 1.
Examples of semester-long experiments from students.

Sample of Semester-Long Experiments Designed by Students
Effects of automobile exhaust on plant growth
Assessing the effects of vinegar and baking soda on wound healing in green onions
Differences in plant growth between hydroponic and traditional gardening strategies
Effects of nutrient-boosted water on plant growth
Population fluctuations of mallard ducks
Effects of burning and freezing on seed bank plant growth
Temperature's effect on mitosis in green onion plants
Assessing the time of year elk reproduce and their reproductive behaviors

research experience could design projects more attuned to a beginner level. The complexity of the research project had no bearing on the graded assignments (Appendix 4), which included a statement of research objectives, mid-semester summary (an introduction and a methods sections), and final write-up (corrected versions of the introduction and methods sections and results and discussion sections). We encouraged students to use common household materials and make observations in safe areas to avoid safety issues. Weekly lab quizzes included a question to relate the topics covered on the quiz to their semester-long project to reinforce making connections between course content and their projects (Appendix 3). Using a questionnaire, we evaluated student perceptions of the semester-long research project (Appendix 5).

CONCLUSIONS

Students performed their semester-long research projects on a variety of topics (Table 1). Students who performed well on the final write-up of their project tended to have high overall course grades (Pearson correlation test, $t = 8.9$, df = 77, $p < 0.001$, Pearson's $r = 0.71$, confidence interval = 0.58 to 0.81). Mean student responses from the questionnaire (Fig. 1) indicate that students agreed strongly that conducting the project helped them appreciate some of the realities of scientific research, such as the importance of a good experimental design and challenges associated with unexpected problems. Some students were unhappy with the specific projects they chose, as some were more ambitious than others, and the workload varied by project.

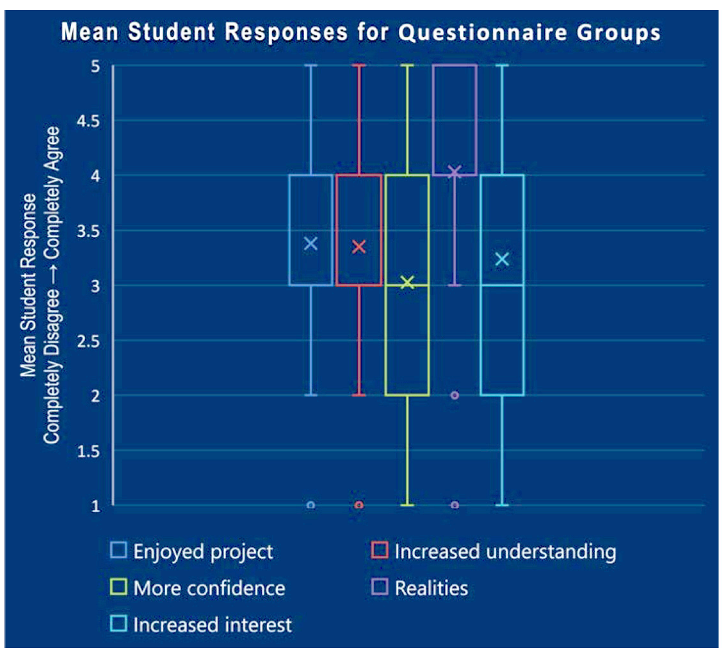

FIGURE 1. Boxplots showing mean student responses on questionnaire ($n = 71$), from strongly disagree (1) to strongly agree (5), for each question (e.g., Did you enjoy the project? Did it increase your understanding of the scientific research process? Did the project help you realize some of the realities of scientific research?).

One student stated, "My experiment did not work out, so I wish I had picked a different one and I think it would have made me enjoy it more and learn more." Although scores ranged from 1 to 5, a majority of students provided positive comments, e.g., "Being able to conduct the whole thing from beginning to end by ourselves was very unique and interesting," and "The semester long project was useful because we could take the experiment as far as we wanted." Students clearly felt a sense of ownership over their project development and execution. Median student responses for the questionnaire were highest (4/5) for questions based on realities as well as enjoyment, indicating students not only learned a great deal from their projects but also enjoyed the process of hands-on, research-based learning. One student commented, "I thought it was a good unique way to include a lot of what we are learning into something hands-on. Made me think more about connections to everyday life." Median scores for other groups (3/5) indicated that students did not strongly agree or disagree that the semester-long research project increased their understanding of the scientific research process, provided them with more confidence as scientists, or increased their interest in biology research.

The project and questionnaire provided instructors with opportunities to discuss common misconceptions in biological research, such as the idea that most learning only occurs when experiments work as planned, which is rarely the case. Instructors could discuss where projects went wrong, whether they could have been corrected with more extensive literature or methods review, or whether there were valuable lessons learned from perceived failures. It is an opportunity to discuss what it means to be successful in biological research and how scientists can either grow from adverse experiences or allow adversity to diminish their interest and/or confidence. As with every challenge in life, it is all about persistence and attitude. Using components of CUREs in the classroom is an easy way to teach students about the process of scientific research in an authentic manner and is easily adaptable to lecture and laboratory contexts with limited resources required.

SUPPLEMENTAL MATERIALS

Appendix 1	Alignment of learning outcomes with semester projects
Appendix 2	Semester project student instructions
Appendix 3	Semester project instructor tips
Appendix 4	Rubric for final experiment write-up
Appendix 5	Student perceptions questionnaire

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