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Assessment of Student Preparedness for Independent Research in a Research-Based Teaching Lab

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Abstract

Authentic engagement in research provides students with skills in scientific inquiry and experimental design that are not easily obtained through traditional, pre-developed laboratories. The goal of this work is to transform a twenty-week traditional laboratory experience for first year MS students in a biotechnology program into a more authentic research experience. The laboratory curriculum focuses on developing students' ability to critically evaluate scientific literature as well as to plan, execute, and troubleshoot experiments. Prior to beginning the course, students were presented with a survey to measure their levels of experience in several skills such as scientific communication and collaboration as well as scientific literature review and comprehension. Students were presented with the same survey upon completion of the teaching lab as well as with a perceived benefits survey to determine whether the lab is effective in developing students' preparedness for independent research. Here we will discuss the development of the pre- and post-survey and the preliminary results from the first iteration of laboratory assessment.

Keywords: CURE, teaching lab, guided inquiry, open inquiry, research experience

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INTRODUCTION

Providing a comprehensive, authentic research experience in the classroom is a challenging endeavor. Many classroom laboratories focus on enabling students to learn common laboratory techniques and safety practices. However, they fail to also address some of the essential components required for independent research such as scientific communication, literature evaluation, critical thinking, etc. One means to address this issue has been through guided inquiry and open-ended inquiry-based laboratories. Guided inquiry involves faculty providing a research question and guiding students to create an experimental design to address the question, while open-ended inquiry has the students develop the question, themselves, and then design the appropriate experiment to address the question (Beck et al, 2014). Similarly, course-based undergraduate research experiences (CUREs), where students address real research questions with no currently known outcome, have also become a popular solution to provide students with authentic research experiences (Lopatto et al, 2008). We have developed a teaching laboratory combining components of both directed inquiry and CUREs with the goal of preparing first year MS students in a biotechnology program to enter research laboratories and perform independent research.

Developing the Biotechnology Teaching Lab

The graduate biotechnology lab consists of two ten-week courses, with a focus on nucleic acids in the first course and proteins and cells in the second course. Initially, students primarily followed a directed inquiry teaching style. Students were first introduced to relevant scientific articles related to a signal transduction cascade involved in leukemia stem cell self-renewal. Briefly, the report hypothesized that the cytoplasmic tail of a transmembrane protein called CD93 is liberated from the full-length molecule, migrates to the nucleus and regulates gene expression through an interaction with SCYL1 (Riether et al, 2021). Students were asked to critically evaluate the literature, including the study described above, and identify limitations in the literature and gaps in knowledge. Students then designed experiments to address those gaps in the form of an NIH-style research proposal. Two specific aims were provided to the students to build upon, and one aim was left open for students to design. For aim 1, the students performed a molecular cloning experiment that encompassed essential molecular biology laboratory techniques (DNA isolation, PCR restriction digestion, ligation, transformation, agarose gel electrophoresis, sequencing, and basic bioinformatics) to generate a bacterial expression vector encoding glutathione-S-transferase (GST) fused to the cytoplasmic tail of CD93 (Zhang et al, 2005). For aim 2, the students were introduced to foundational skills in biochemistry by expressing the protein in *E. coli* and analyzing the purified material. They were also introduced to foundational skills in mammalian cell biology and used their GST-fusion protein to attempt to pull-down SCYL1 from a cell lysate from the K562 leukemia cell line. In the final three weeks of the course, students took a CURE-based approach to design the final aim 3 to investigate some aspect of a CD93 signal transduction in a K562 cell. Additionally, students presented their laboratory results as a final poster presentation with publication quality figures to showcase their final work. NIH-style proposals and posters were completed iteratively as low-stakes assignments throughout the respective courses with feedback from peers and instructors, with final higher stakes products at the end of the courses. Assessments encompassed participation (lab work and attitude), projects (proposal or poster), weekly quizzes, and lab reports. Figure 1 outlines the course and Table 1 outlines student learning objectives (SLOs) for skills students should have by the end of the course.

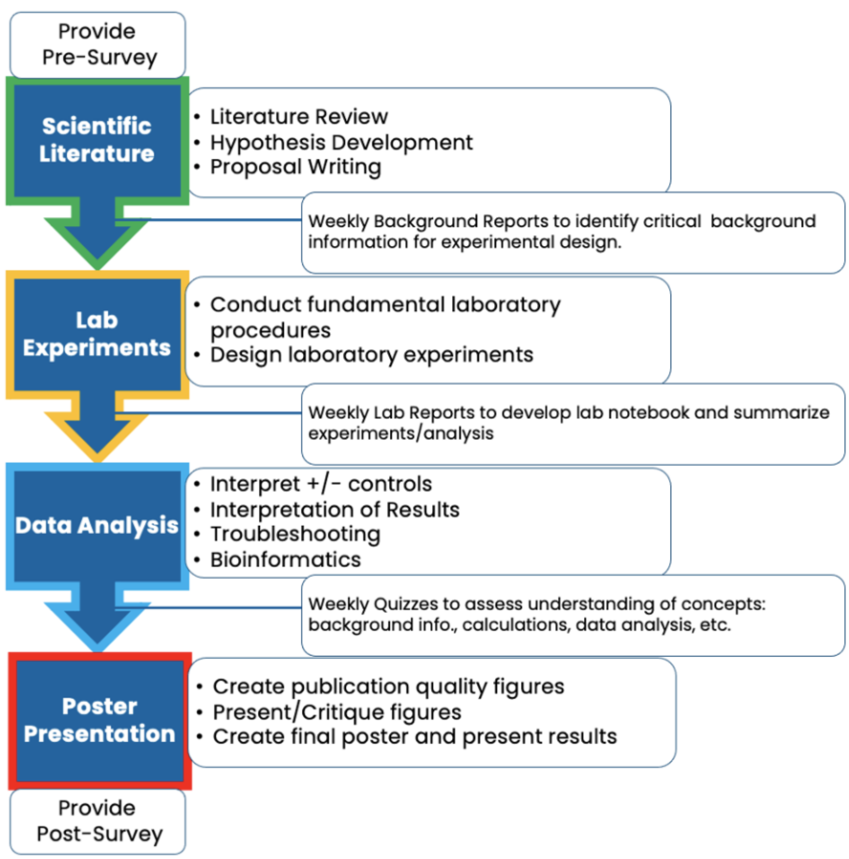


Figure 1. Outline of the teaching laboratory course

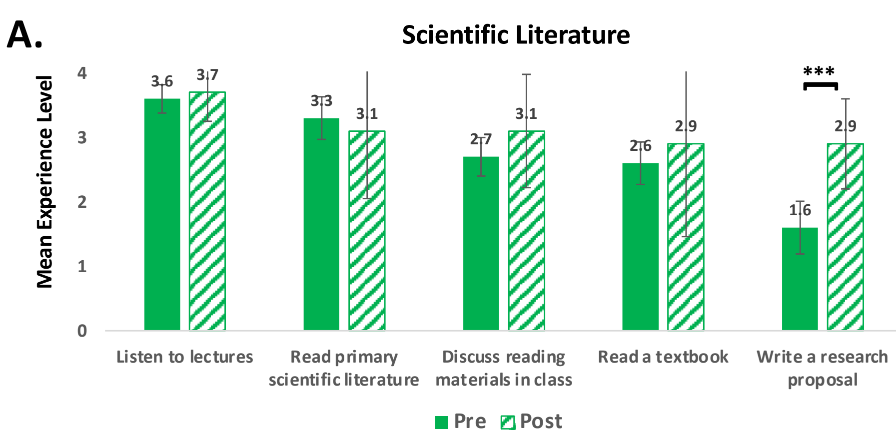
Table 1. Student Learning Objectives

By the end of this course, students will be able to:	
SLO1	Identify the critical background information necessary for experimental design.
SLO2	Apply scientific theory and methodology to safe laboratory practice.
SLO3	Design appropriately controlled experiments.
SLO4	Successfully conduct fundamental laboratory procedures.
SLO5	Analyze, evaluate, and troubleshoot experimental results.
SLO6	Develop a research proposal.
SLO7	Demonstrate scientific literacy by reviewing scientific literature and critiquing gaps in knowledge.
SLO8	Generate figures of publication quality for professional presentation.
SLO9	Generate and present a scientific poster.

Results

Student Experience Survey

At the beginning of the biotechnology lab, students were surveyed using the validated Survey of Undergraduate Research Experiences (SUREs) developed by Lopatto to assess their current experience levels in numerous areas related to scientific research (Lopatto, 2004). They were presented with the same survey upon completion of the twenty-week teaching laboratory to evaluate the effectiveness of the teaching lab curriculum to prepare students for independent research (Figure 2). In the category of 'Scientific Literature,' students perceived a significant increase in experience level in "writing a research proposal" (figure 1a., $p \leq 0.0005$) whereas no significant differences were identified in areas associated with most undergraduate programs including "listen to lectures" or "read a textbook." This data suggests that students benefit from advanced scientific writing associated with research laboratory experience. In the category of 'Lab Experimentation,' students perceived a significant increase in experience level in "be responsible for a part of the project," "projects in which students have some input," and "project entirely of student design," whereas no significant differences were identified in areas associated with most undergraduate programs such as "collect data" or "work on problem sets" (figure 1b). This suggests that students are benefiting from the combination of guided-inquiry and a CURE-based approach in which students design their own aim to then investigate a problem. Similarly, in the category of 'Scientific Presentation,' students perceived a significant increase in experience level in "critique the work of other students" and "present posters (figure 1d.), suggesting a greater confidence in advanced scientific communication.



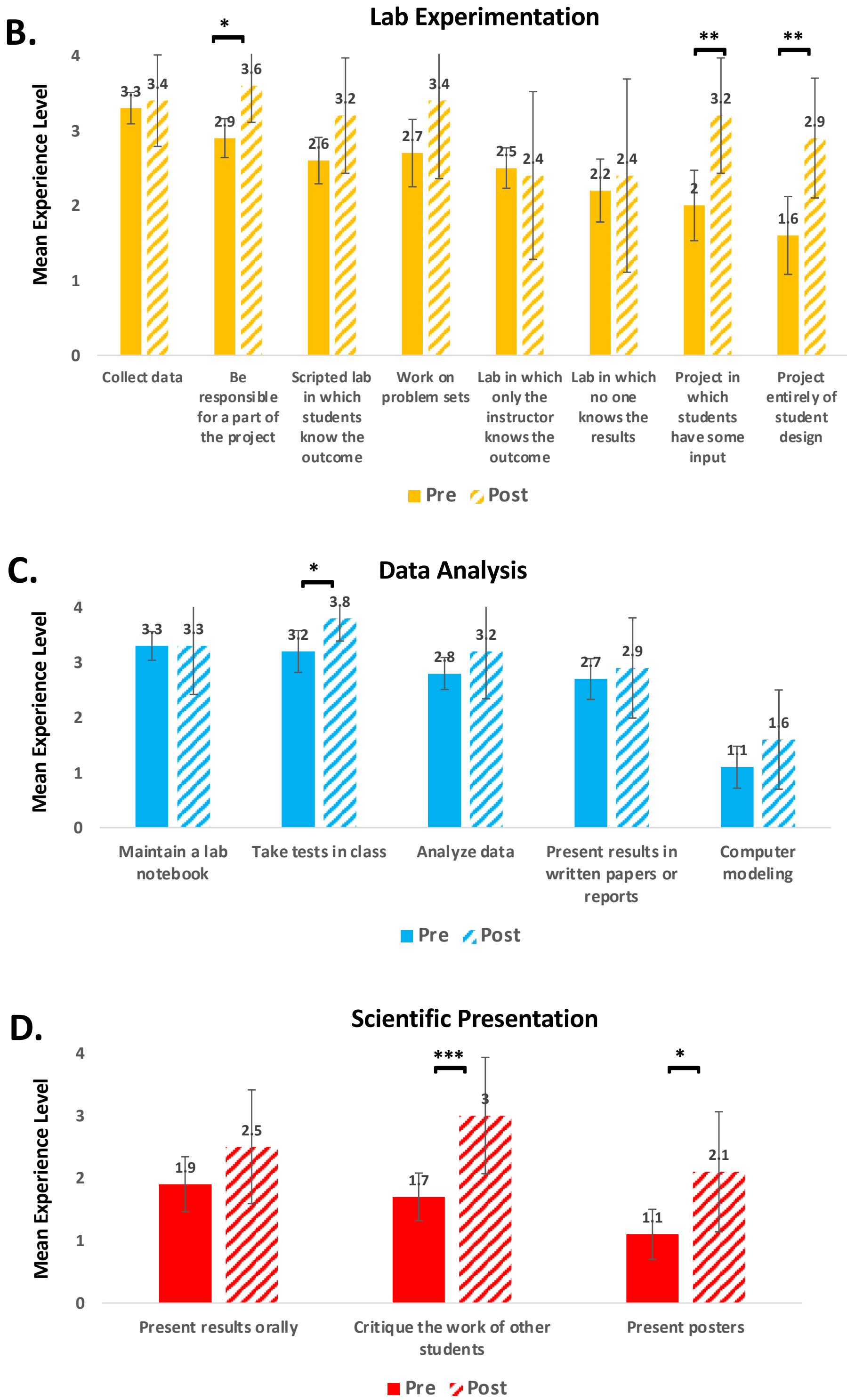


Figure 2 (A-D). Pre- & Post-Survey Results. Students (n=14) were provided with statements related to laboratory course work and asked to rank their experience level. Experience levels were assigned the following values for quantification: None (0), Little (1), Some (2), Much (3), and Extensive (4). Responses were averaged and grouped according to scientific literature (A), lab experimentation (B), data analysis (C), and scientific presentation (D). Data labels represent average experience, error bars represent standard error of mean. Statistical analysis was completed with Excel. A T-test was used to determine significant. * represents p values ≤ 0.05, ** p ≤ 0.01, *** p ≤ 0.001.

Student Perceived Benefits Survey

Students were also presented with a perceived benefits survey after taking the course to determine whether they felt the teaching laboratory course helped them develop in their preparedness for independent research (Figure 3). The results of the perceived benefits survey were generally positive, as all statements scored above a moderate gain, with the majority of statements (15 out of 21) indicating a large or near very large gain. As a major goal of the teaching lab is to improve students' preparedness for independent research, the survey shows that students perceive a large gain in their 'understanding of the research process in your [their] field' (Figure 3, mean 4.2/5,) and in their 'readiness for more demanding research'(mean 4.1/5). While the teaching lab aims to address some of the essential components required for independent research that traditional labs sometimes fail to do (e.g., scientific communication, literature evaluation, critical thinking), it is similarly important to continue to provide students with knowledge in common laboratory techniques. Students reported the highest perceived gain on the survey in 'learning laboratory techniques,' (mean, 4.7/5) demonstrating that the teaching lab continues to develop students further in their knowledge of laboratory techniques as well as addressing some of the other essential components of research.

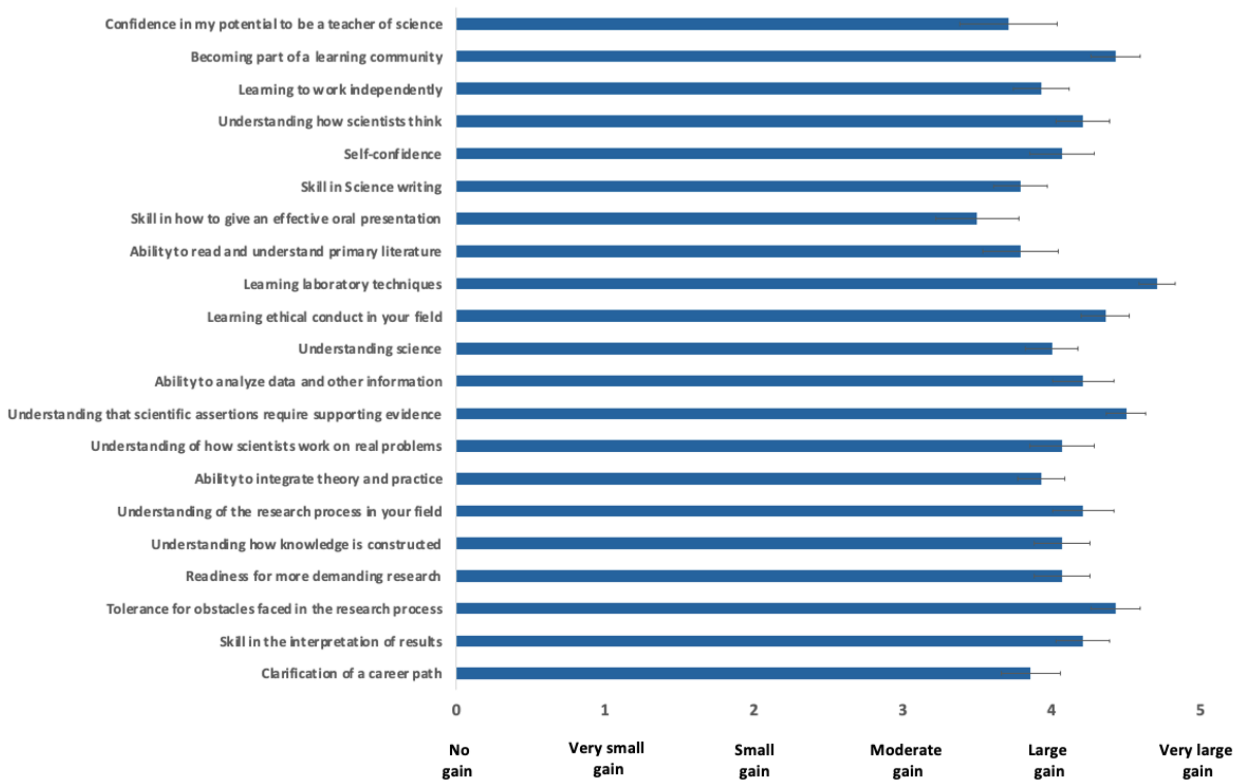


Figure 3. Students (n=14) were provided with statements related to their preparedness for laboratory research and asked to rank their perceived benefits after taking the course. Gains were assigned the following values for quantification: No gain or very small gain (0), small gain (1), moderate gain (2), large gain (3), and very large gain (4). Responses were averaged. Error bars represent standard error of mean. Statistical analysis was completed with excel.

Conclusions

Here we outlined a 2-course biotechnology lab for first year MS students with a goal of preparing the students for independent research in a faculty laboratory. Preliminary survey data from our first cohort (n=14 students) suggests that the laboratory was a high value experience with students making measurable gains in advanced research skills including writing research proposals, designing experiments, critiquing the work of others and presenting research posters. Future goals will be to survey additional cohorts, as well as develop an instrument to assess faculty perception of student preparedness for research.

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