Tips and Tools

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The Best of Both Worlds: Discovery-Driven Learning through a Lab-Seminar Approach

Marisa S. Egan,[a] Karen Hogan,[b] Julie Maupin-Furlow,[c] and Mechthild Pohlschroder[b]
[a]University of Pennsylvania, Perelman School of Medicine, Department of Microbiology, Philadelphia, Pennsylvania, USA
[b]University of Pennsylvania, Department of Biology, Philadelphia, Pennsylvania, USA
[c]University of Florida, Institute of Food and Agricultural Sciences, Department of Microbiology and Cell Science, Gainesville, Florida, USA

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INTRODUCTION

In college, introductory microbiology lecture courses are often taught together with a lab section that introduces students to techniques used to cultivate and characterize microorganisms and underscores concepts taught in lecture. Research has shown that incorporating discovery-driven experiments into lab courses, rather than highly structured "cookbook" experiments, leads to greater student engagement, enhanced critical thinking skills, and better learning outcomes (1–6). Transposon screens and selections and subsequent characterization of mutants lend themselves well to discovery-driven laboratory exercises that demonstrate fundamental features of microbiological processes, from motility and surface adhesion to stress responses (7–9). Students can be involved in the design of such screens and selections, providing them with experience in using proper controls, determining appropriate phenotypic assays, and identifying ideal conditions for each assay (9). This approach requires that students gain a more advanced understanding of the underlying scientific principles than needed for the typical lab course. Such information can be obtained in seminar courses, which provide students with the background needed to master the analysis of the primary literature. Generally, seminar courses are taught independent of lab courses. Here, we describe a course that includes both seminar and lab sections. The seminar section establishes a foundation built on the analysis of primary literature that will be applied in the lab section. At the same time, the lab section is designed to facilitate the understanding of topics raised in the literature through experimentation.

PROCEDURE

In our "Microbial Diversity and Pathogenesis" course, we set two primary learning objectives for our students:

1. Learn fundamental microbiology concepts through analysis of the primary literature and application of experimental techniques.
2. Apply this knowledge to discovery-driven research project and subsequent hypothesis-driven research proposal to empower students to successfully conduct and evaluate scientific research.

Students enrolled in this course were predominantly advanced undergraduate students majoring in the biological sciences. While familiar with basic experimental techniques through their introductory biology courses, students had limited experience with primary literature analysis and grant-writing.

To convey basic concepts of microbiology, we presented traditional lectures in concert with seminar-style class discussions of primary literature related to the topic presented in each lecture. In the lab section of the course, students were eased into an understanding of basic lab methods by carrying out simple experiments that reinforced concepts presented in the primary literature, ultimately providing students with a solid foundation for discovery-driven experimentation (Appendix 1). For example, the students read about the decade-long technically challenging yet ultimately successful cultivation of an Asgard archaeon in an enrichment culture (10), while concurrently learning to isolate bacterial species from a mixed culture of *Micrococcus luteus* and *Serratia marcescens* (see Appendix S1 in the supplemental material). By performing experimental

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Address correspondence to University of Pennsylvania, Department of Biology, Philadelphia, Pennsylvania, USA. E-mail: pohlschr@sas.upenn.edu.
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techniques used in the primary literature, students can contextualize the published data.

Additional skills are fostered through this approach. As the students read and analyze primary literature, they develop their scientific literacy skills. Initially, papers, or even a few figures from a paper, highlighting simple procedures were read and analyzed to provide students with a gradual introduction to the primary literature. As the course proceeded, papers containing more complex protocols and techniques were assigned (see Appendix S1). With each paper, the students were provided with questions to consider as they read (see Appendix S2). During class time, students met in small groups to discuss the assigned literature as a means of promoting their scientific communication skills. To that end, students were encouraged to dissect and critique the papers. This exercise nurtured critical thinking in students, empowering them with the confidence needed to both appreciate and critically evaluate the published findings. "Low stakes" assignments were used to assess how well students comprehended the assigned papers, such as asking students to propose possible follow up studies. We found that students often enjoyed these assignments, as they engaged their critical reasoning skills and creativity through these thought experiments.

The second learning objective was for the students to apply the microbiology concepts they learned in the first half of the class to a scientific research project. To this end, students posed a research question based on results presented in a research paper and designed and carried out a genetic screen to answer their question (see Appendix S1). We used a transposon mutagenesis screen to deliver an inquiry-based lab experience, since this approach emphasizes several basic microbiology concepts (8, 9) (see Appendix S3). Screens and selections also allow students to investigate various scientific questions and rely upon concepts taught earlier in the course (8, 9) (see Appendix S3). First, students discussed Schiller et al. in small groups, came up with a research question and wrote a preproposal addressing the question and developing a hypothesis. Then, we directed the students toward the best screen to use, discussed how the screen works, and pointed out things to consider when setting up the screen. Schiller et al. describes honeycomb formation of *Haloferax volcanii* liquid biofilms upon reduction of humidity (11), so we had the students construct a screen to search for mutants unable to form honeycombs, as well as carotenoid-forming mutants and mutants defective in biofilm formation. Time in this 0.5-credit course was limited, since the students only met synchronously for 1.5 h per week. A 1-credit course would allow students to spend significantly more time on their projects, including more direct troubleshooting to determine optimal screening conditions and following up on these screens by sequencing the genomic DNA of the selected mutants and phenotypic characterization of these mutants. All experiments comply with the *American Society of Microbiology Guidelines for Biosafety in Teaching Laboratories* (https://asm.org/Guideline/ASM-Guidelines-for-Biosafety-in-Teaching-Laborator).

Students next generated their own hypothesis-driven research proposals. In their proposals, students incorporated concepts learned through reading and class discussions of primary literature and experimental techniques experienced during their lab work (see Appendix S4). Since our students did not have enough time to identify genes of interest, we asked them to write their proposals on genes identified in published literature (12). We encouraged students to include rigor and reproducibility in their proposals and consider factors such as feasibility, available resources, and allotted time. Students could also make judicious use of preliminary data collected from their transposon insertion mutagenesis screen, when applicable (see Appendix S4). We stressed that since the preliminary data generated was both novel and gathered collectively, it should be shared with the entire class. The data were then discussed, analyzed, and interpreted collaboratively, allowing each student to offer their unique perspectives while acknowledging that science requires teamwork and effective communication. Ultimately, we aimed to have students understand the significance of Isaac Newton's insight based on his experience: "If I have seen further it is by standing on the shoulders of giants."

CONCLUSIONS

The innovative microbiology course described here combines elements of a lab-based class and a seminar-style one. We find that the power of this course lies in the synergy between lab and seminar elements, which generates heightened student engagement. Based on our observations, we noted that students become familiar with primary literature through active reading. There were also observations of students critically analyzing data and discussing them in small groups. We noticed that through such literature analysis, students learned about particular experimental techniques applied to a research question and even used these same techniques to contextualize data presented in subsequent papers. In addition, we observed students apply this knowledge to crafting their own hypothesis-driven research proposal. Most importantly, students learned in group settings and therefore experienced the collaborative nature of scientific research. Carl Woese wisely remarked, "Our task now is to resynthesize biology; put the organism back into its environment; connect it again to its evolutionary past; and let us feel that complex flow that is organism, evolution, and environment united. The time has come for biology to enter the nonlinear world." We find that this course embodies that quote, allowing students to experience the depth and breadth of the microbial microcosm through a holistic educational experience.

SUPPLEMENTAL MATERIAL

Supplemental material is available online only.

SUPPLEMENTAL FILE 1, PDF file, 0.2 MB.

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