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BOARD # 34: Work-in-Progress: A Novel Project-Based Molecular Biology Experimentation and Design Laboratory Course Using Participatory Design to Promote Student Engagement

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Introduction

Traditionally, instructors have designed courses without substantial input from undergraduate students. However, recent work has shown that participatory design of curriculum results in more engaging, effective courses [1] and that students who engage in participatory design report a high level of engagement and confidence in the course material [2, 3].

In this work-in-progress, we describe the design and implementation of a novel, project-based molecular biology experimentation and design lab course. A key feature of the course is participatory design, which can be defined as the process of involving end-users in all steps of the engineering design process. We used participatory design in two ways: (1) the instructor co-created the course with two senior undergraduate students, and (2) students enrolled in the course are continuously involved in decisions at every step of the project.

The goals of our paper are: (1) to encourage instructors to involve undergraduate students in participatory design for course development and (2) to provide curricular materials for others to implement a novel, synthetic biology lab course. We provide instructor observations and informal student feedback; thus, this work was determined to be exempt from further review by our institution's IRB. The following link provides access to all course materials are provided including: syllabus, lab protocols, assigned readings, quizzes, class presentation slides, lab report template, homework, and guiding questions for each lab report: https://tinyurl.com/yx3f2czp.

Course Overview

This 10-week course provides advanced training in molecular biology, with an emphasis on engineering design in experimental practice. Typically, the course enrolls 44 students (approximately 22 students per lab session) who are in their second or third year. Students meet for one 90-minute lecture and one 3-hour lab per week.

This is a project-based laboratory course, which means that each lab procedure builds on the previous week's lab. Project-based learning (PBL) has been shown to enhance student engagement and understanding of material [4]. Students engage in participatory design of the lab project by making experimental design decisions throughout the quarter. Students will make most materials used in lab, including bacterial growth media, PCR primers, and competent cells with appropriate genetic profiles for different cloning steps.

Course assignments include: weekly lab quizzes, pre-lab write-ups, lab participation and technique, and lab reports. At the end of the quarter, student teams will give a 10-minute "journal club" presentation of a primary research article that is directly related to the lab project.

Overview of Lab Project

The students complete a synthetic biology project involving "clonetegration," or the one-step cloning and integration of a plasmid carrying a cloning module and integration module [5]. Briefly, we use the pOSIP-KL-mcherry plasmid [6] carrying the fluorophore mcherry for the initial step of integration by a viral integrase enzyme at a known attachment site in the *E. coli* genome After integrating the entire plasmid into the genome, we flip out the integration module (including the integrase enzyme and antibiotic resistance) using the pE-FLP plasmid [7], so that only the cloning module including our gene of interest remain integrated in the genome. We confirm successful integration and flip-out steps by colony PCR. (See Appendix A for complete lab schedule.)

Participatory Design

This course involves participatory design for two populations: (1) the undergraduate students who co-designed and co-taught the first offering of the course, and (2) participatory design of lab procedures and troubleshooting decisions by students enrolled in the course.

Participatory Design by Students Co-teachers. The course curriculum, including lab protocols, class slides, lab quizzes, was co-designed with two undergraduate students in iGEM (international Genetically Engineered Machines), who designed the lab project based on some of their prior iGEM work at our institution. In addition to providing much-appreciated expertise in the topic and valuable troubleshooting skills, the iGEM students added useful insights to the instructor. For example, the students recommended going over the weekly quiz as a class to enhance student understanding of the protocols. Going over the quizzes as a class was beneficial, as many students in their end-of-course evaluations stated that the quizzes really helped them understand the material and helped them write better lab reports.

Importantly, we designed the course with the goal of teaching what these senior iGEM students wished they had learned before taking on their iGEM capstone project, including practical skills such as using proper sterile technique to make bacterial growth media. The students helped the instructor realize what the students were capable of, such as when they suggested making the final presentation in “journal club” format. Many former students have told the instructor after taking the course that learning practical lab skills and communication skills have been very useful when they entered research or capstone labs.

In the first offering where the iGEM students co-taught the course, the students enrolled in the course reported that the student co-teachers made the course more accessible and relevant. Students are always excited to learn that the project is based off of iGEM work and that the labs were designed to teach students what they will use in future lab settings. We are convinced that the participatory design component of the course is a major reason we get student buy-in for the lab protocols and overall project.

Participatory Design of Lab Protocols by Students Enrolled in the Course. The student co-designers of the course suggested that we also use participatory design for students enrolled in the course. The following are examples of how we facilitate participatory design:

(1) Each week we provide resources and ask students to write their own protocol before lab, instead of providing a step-by-step protocol or “cookie cutter” instructions.
(2) Students execute the project with only minimal supplies provided. Students make bacterial growth media, buffers, and their own chemicompetent cells.
(3) In each lab, we discuss factors to consider when designing experiments and students decide how to proceed. Students make design decisions such as which E. coli strain to use with specific plasmids.

(4) Students design experimental controls and design PCR primers.
(5) Students complete lab quizzes collaboratively, and we review answers as a class. We provide students with guiding questions for troubleshooting experiments.

Since the first offering of the course, we have implemented several changes that seem to increase student engagement, preparedness, and confidence level in the lab. These include:
(1) Requiring students to include a graphical abstract [1]in their lab reports.
(2) Student reflection at the end of every lab report where students articulate something they learned and feel confident with, and also anything that is still unclear.
(3) Guided post-lab analysis, including asking students to analyze hypothetical results or asking students how the results would have been affected if they had made a hypothetical mistake in the procedure.

Although students no longer co-teach the course, the instructor continues to leverage undergraduate lab assistants. For example, the instructor recruits diverse undergraduate lab assistants so that students can interact with people of diverse identities and backgrounds in BME. We observe that students find value in asking their peers not only about the course material but also about their experiences in the BME program or research.

As the instructor has increased the role and visibility of undergraduate lab assistants in the course by having them demonstrate particular lab skills and help students use lab equipment, the instructor observes striking improvements in overall student engagement, mastery of techniques, teamwork, and confidence in lab performance.

Conclusion

We describe the successful design and implementation of a project-based lab course, using participatory design in both (1) students co-designing the original curriculum and (2) currently enrolled students helping with experimental design within the course project.

We did not follow any particular framework in the participatory design of the course. However, we were guided by the students' question: "What did we wish we had learned before we began capstone research?" Our focus on this perspective was very powerful, and helped the instructor better gauge student interest and what students are capable of doing in an introductory lab series. The instructor has continued to re-design aspects of the curriculum based on student feedback and performance (e.g., requiring a graphical abstract and reflection in lab reports, and providing guiding questions for lab reports). Students provided very positive feedback on the participatory design of lab experiments., Students appreciate the deeper level of understanding required for experimental design, including troubleshooting and designing appropriate controls.

Overall, we found participatory design to be a powerful tool in curriculum design and student engagement in the lab experiments. We aim to provide a resource for other instructors who are interested in participatory design of courses, providing participatory design experiences for students in a lab course, or implementing a novel course in synthetic biology. In the future, we will collect data on student experiences to identify the aspects of participatory design that students find most helpful.

Appendix A. Example Lab Schedule

Week	In your lab session: Pre-lab Due and Quiz
1	Welcome and Introduction, Lab Safety No pre-lab due
2	Lab 1: Making Media and Pouring Plates
3	Lab 2: Isolation of plasmids pOSIP-KL-mcherry and pE-FLP
4	Lab 3: DH5-alpha Chemicompetent cell prep
5	Lab 4: Transformation #1: pOSIP-KL-mcherry in DH5-alpha competent cells
6	Lab 5: DH5-alpha-pOSIP-KL-mcherry Chemicompetent cell prep TBD: Making Media and Pouring Plates #2
7	Lab 6: Transformation #2: pE-FLP into DH5-alpha-pOSIP-KL-mcherry competent cells
8	Lab 7a: Colony PCR
9	Lab 7b: Analyze PCR products on gel to confirm Clonetegration
10	Journal Club Presentations
Finals Week	No exam

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