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Building better labs through pandemic teaching: First-year lab course changes that could work for you

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The transition to online learning was a major challenge for post-secondary instructors. Amidst the shift to emergency online/remote learning, our team of lab instructors took this as an opportunity to redevelop our first-year lab course more permanently. Our starting point was to identify and address gaps, overlaps, and outdated material in the course. In our redevelopment, we aimed to include inquiry-based learning, to promote higher order thinking, and to build student research skills (Parappilly et al., 2013, Clemmons et al., 2020). Specifically, we chose to focus on major highlights of the scientific process: experimental design; data collection; data analysis & interpretation; and then integrating these three into a team project. We aimed to reflect these changes throughout the semester, as well as in assessments and the lab exam. Here we present four major changes we made to our first-year labs that could work for any biology lab, whether a course is offered online or in-person.

Course Logistics

Labs were run synchronously: four students video conferenced and worked together on shared documents on the cloud weekly. Labs were run as 2-hour sessions at Simon Fraser University (SFU) and 3.5 hours at Fraser International College (FIC). Students submitted an individual pre-lab before lab, to become familiarized with lab topics. During the lab, teaching team members interacted with the students regularly, providing feedback throughout the lab period.

Principles and Practice of Experimental Design

In moving away from the face-to-face, hands-on course experience, we decided to emphasize experimental design and data analysis, to improve understanding of these fundamental concepts. Here we implemented dual themes of 1) investigation of an experiment/biological processes, then 2) practice with experimental design in most labs, in a scaffolded manner (D'Costa and Schlueter, 2013). Students were given information on the topic of the week and tasked with answering various theory- and method-based questions regarding a given experiment. Then students were asked to design a modified experiment, based on the material they just covered. An example of this is found in our Cell Membrane Structure and Function lab; students investigated the how and why some molecules that can cause red blood cell lysis, then were asked to set up an experiment to test a "Mystery Compound X" and identify the proper controls that would be required in this circumstance. This general structure of investigate, then design, follows Bloom's taxonomy: students start off with lower-level tasks (remember, understand), then use what they learned to design an experiment (apply, create). Based on the authors' experience with students and their understanding of lab material, this stepwise approach has greatly increased the students' understanding of scientific concepts, particularly ones that are challenging to visualize. In a feedback form given to former students, over 66% found their understanding of experimental design improved by designing different experiments regularly in lab, and 60% strongly agreed that they were confident they could design a successful experiment in the future.

Simulations as Teaching Tools

In the absence of experiments, we also sought to incorporate the use of simulations in the remote learning lab due to their effectiveness as teaching tools (D'Angelo et al., 2014). While different iterations of lab contained different resources, the Photosynthesis simulation by Jon Darkow (https://sites.google.com/site/biologydarkow/) is one that stayed consistent throughout the 4+ terms online. Students would use the simulation throughout lab to collect data and manipulate parameters in real time. We found using simulations helped students understand complex processes that may be difficult to recreate in the in-person lab space, giving students a deeper understanding of specific concepts. We have also used various gel electrophoresis simulations from the Genetics Science Learning Center and LabXchange, as well as the Bioman Respiratory Journey game (https://biomanbio.com/HTML5GamesandLabs/Physiologygames/respiratory_journeyhtml5page.html), among others. Students enjoyed working with simulations which increased their engagement. Over 80% of students found the photosynthesis simulation we used to be useful. Students reported finding value in manipulating variables and observing the effects in real time. They also stated this simulation helped them to visualize the complex processes of photosynthesis, increasing their understanding. Students also believe simulations would be helpful for increasing their understanding of a variety of complex topics covered in this course (gene expression, DNA replication, excretory systems, etc.).

Data Analysis and Interpretation

Along with an increased emphasis on experimental design, we also increased the amount of data analysis and interpretation students do weekly in lab, in a scaffolded manner. During the re-design of our labs, we asked more direct and specific questions regarding data analysis. An aspect we introduced to our lab was providing students with real time data; students design an experiment, and instructors have pre-constructed data sets that are given to students, in lieu of collecting the data themselves due to the absence of experiments. This was used in our Enzyme lab, after student's setup an experiment to test the method of inhibition of an unknown inhibitor; students can design the experiment in a few different ways and are given a data set to match their setup. Simulations used in lab also provided data, with the benefit of seeing the effects of experimental manipulations in real time. Our focus on data analysis, along with providing regular feedback throughout lab, appears to have improved students' capacity to interpret data. Sixty percent of student respondents strongly agreed that their ability to interpret and analyze data improved over the semester, and over 53% strongly agreed their confidence in this task increased over the semester as well.

Team Projects

Building on the themes of experimental design and data analysis, we decided to incorporate a group scientific project into the course to help our students take on an active role in their learning (Luckie et al.,2004). This gave students an opportunity to take a project from start to finish designing a real-life experiment, planning its execution, collecting data, and sharing their findings. While initially this was selected as a means for students to get some hands-on experience doing science, we have kept this project due to its overall success. We have dedicated three labs over the semester to this project. During the first month of the semester, students will have the Introduction to Projects lab, where they pick a topic and plan out their procedure. Later, students have a Data Analysis lab, where they answer questions about their data and prepare for their final presentations. Here we introduce students to graphing, so they can include their graphed data as part of their final documents. Finally, at the end of the term, students present the work they did in a conference-style format. Students are also required to summarize their work in a scientific abstract. Students are asked to review their teammates and presentations from other groups. Overall, students enjoyed this project. Eighty percent of students agree that preparing and giving presentations, as well as observing and critiquing others increased their confidence in giving future presentations.

Over 70% of students agree that designing and doing experiments in this format helped increase their understanding of experimental design and data collection. Also, over 40% of students at SFU who performed this group project found they were more interested in doing science/research than before the class started.

Keywords: inquiry-based learning, data analysis, experimental design, scientific process

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