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A Remote-Learning Framework for Student Research Projects: Using Datasets to Teach Experimental Design, Data Analysis and Science Communication

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Abstract

Remote learning often requires an alternative to hands-on, student-designed research projects. To this end, we created a package of scaffolded assignments to support introductory students through the research process using datasets from past student projects. These assignments provide opportunities for active practice and feedback on skills in experimental design, data analysis, literature review, and scientific communication. While we created the assignments to be heavily guided and focused on organismal biology to support students in our particular course context, the documents are highly customizable to meet the learning objectives for other course formats, subjects, and levels.

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Supporting Materials: Supporting Files S1. Remote Learning with Datasets - Student Datasets; S2. Remote Learning with Datasets - Experimental Planning Document; S3. Remote Learning with Datasets - Data Analysis Document; S4. Remote Learning with Datasets - Literature References Document; S5. Remote Learning with Datasets - Project Summary Script and Presentation Document; and S6. Remote Learning with Datasets – Research Poster Template.

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INTRODUCTION

Students in inquiry-based lab courses show gains in the "essential components" of mentored research, which include reading primary literature, collecting and analyzing data, and communicating results via written and oral presentations (1-3). Targeted skill-building, particularly in the context of experiential learning in inquiry-based lab courses, can improve student attitudes towards the process of science (4). Our learner-centered *Introduction to Organisms* lab course supports authentic inquiry and student proficiency in the foundations of experimental research. In the first half of our course, students learn scientific skills through instructor-designed inquiry activities examining form and function of local organisms. In scaffolded lab assignments, students learn to manage data sheets, create and interpret graphs, generate descriptive statistics and perform statistical tests, write simple results texts, and connect their findings to those in relevant published studies. Because these competencies are introduced progressively and practiced repeatedly over several weeks, students are well prepared to independently apply them to their own projects in the latter half of the semester. Student groups (3-5 students) design novel, ecologically relevant "follow-up" experiments using a model organism from a previous lab activity. They collect and analyze their own data, and ultimately communicate their findings to peers and invited biology department colleagues in an ePoster session on the final lab day.

There has been a trend of growing enrollments for distance education (or "remote learning") across all of higher education—as of Fall 2016, 31.6% of all students in higher education were taking at least one distance course (5). In the face of COVID-19, there has been an added urgency to implement online coursework, either to supplement or replace traditional face-to-face lessons, including labs. Online labs can engage students with experimental design and data collection through modified instructor-created labs, virtual lab simulations, and/or activities associated with at-home hands-on lab kits (6, 7). However, providing STEM laboratory courses online can present a range of challenges in terms of time, materials, and cost, and can be perceived to lack the rigor of in-person lab courses (8). Despite the challenges, online lab activities and modules have been shown to effectively promote learning of scientific skills (9, 10, 11). As coursework shifts online during the pandemic response and into the future, vetted remote teaching resources that meet the modified online lab learning objectives become increasingly valuable. Here we describe our strategy for modifying our course's inquiry-based introductory biology lab project for the remote setting. We provide a "package" of scaffolded assignments we designed to target research skills using existing datasets from original student-designed experiments.

Intended audience

We implemented this assignment package in an introductory organismal biology lab for biology majors at a mid-size public state university. However, because it is skills-based rather than content-specific, the assignments are highly adaptable to any course that includes learning objectives rooted in the scientific process. Some prerequisite skills are needed to complete the assignments including formulating hypotheses, organizing spreadsheet data, creating a figure, performing statistics, writing results paragraphs, and interpreting scientific literature. If these skills are taught throughout the semester, students can complete the assignments as an independent or group "capstone" project over several weeks near the end of the semester.

We used this assignment package for culminating course projects in two different course formats. During Spring 2020, students in our introductory biology lab course independently completed one document per week in the final weeks of the semester in a fully asynchronous online course format (after moving remote mid-semester during the COVID-19 response). During Fall 2020 our lab course was synchronous and online. Students worked in groups in Zoom breakout rooms and collaborated on one document per week in the final weeks of the online course.

REMOTE PROJECT DOCUMENTS: RATIONALE & TEACHING TIPS

1. Dataset selection

Because students cannot complete the hands-on group-designed experiment in an online lab format, we provide students with data from past student-designed experiments and allow them to choose the dataset they find most interesting (three samples provided in Supporting File S1: Remote Learning with Datasets - Student Datasets). These data reflect the organisms used in our in-person course and our introductory students' topic interest and level of experimental sophistication. You could use the datasets provided, select data from past student experiments in your own courses, or mine data on relevant topics from published papers or citizen science projects (e.g., iNaturalist, Zooniverse). Additionally, we provide students with a few references for research articles relevant to each student experiment. See more on using these resources in the Literature References Document (section 4, below).

2. Experimental Planning Document

The Experimental Planning Document (Supporting File S2: Remote Learning with Datasets - Experimental Planning Document) engages students in a "reverse" planning process according to their dataset—a helpful starting place since students are not able to design an experiment collaboratively in the lab. Students initially learn more about the model organism that was investigated. Then, from the data, students determine the experimental question and rationale, and consider the relevance of the model organism for this experiment. Students generate an experimental hypothesis and, without analyzing the data, describe what experimental outcomes would support their hypothesis. If your students already have experience with searching scholarly websites and literature, you can ask them to provide references to supporting information for the rationale and hypothesis prompts. Students then review their dataset to identify the independent/dependent variables and state the groups being compared (including the control group, if applicable). Note that the datasets we provide show the raw experimental data for all replicates, which allows students to determine the sample size for each experimental group. If you use summary data or tables from the results section of a published study, you may need to provide your students with the sample size for each group.

It may be helpful to have students create an experimental design graphic, incorporating a schematic of the conditions for each treatment group with the number of replicate samples measured in each group (they can use PowerPoint, the Google Drawing extension, or an online whiteboard tool). You could also ask students to sketch a graph of the predicted results, based on their hypothesis and expected outcomes.

3. Data Analysis Document

In the Data Analysis Document (Supporting File S3: Remote Learning with Datasets-Data Analysis Document), students identify the most appropriate type of graph to illustrate the data and demonstrate an understanding of which variables (independent, dependent) should be displayed on the X-axis and Y-axis. They calculate summary statistics (mean and standard deviation, sample size) using calculators or formulas in Microsoft Excel, or, alternatively, you could provide them with summarized data. Students then graph the data with proper axis labels, error bars and figure captions according to science writing conventions. Additionally, students perform an appropriate statistical test to evaluate the experimental hypothesis articulated in the Experimental Planning Document. If a specific statistical program is not taught in your class, free online statistical calculators (two examples provided) can be used with ease after a brief orientation. Finally, students write a formal results paragraph to objectively describe the data displayed in the figure using the conventions of a scientific journal and include support from the statistical tests. A sample grading checklist has also been provided.

4. Literature References Document

The Literature References Document (Supporting File S4: Remote Learning with Datasets - Literature References Document) requires students to use scientific literature to glean background information in the research area associated with their chosen experiment and to practice analyzing and making connections to published results. In our introductory course, this is the first time students work with full research journal articles, so we directly provide them with journal articles that are readable and relevant to their chosen experiment. If your students have practice searching scholarly databases and selecting research articles, you could add this step to the activity rather than providing them with the articles.

Students begin by identifying basic article information (including author locations is a great way to highlight the diversity of scientists and global nature of the scientific community). If students have been taught formatting for in-text citations and literature cited sections (e.g., APA format or a specific journal format), prompts for practicing those skills could be added here. Students are then guided to review the article's Introduction/Background to collect information on the research relevance and model organism(s) and determine the specific aims of the published study. Lastly, students are directed to skim all data in the Results section and select one figure or table (or partial figure/table) to analyze that is relevant to their experiment. They identify the variables and experimental groups in the published results, describe the authors' findings, and compare/contrast them to their own.

5. Project Summary Document

The Project Summary Document (Supporting File S5: Remote Learning with Datasets - Project Summary Script and Presentation Document) guides students to integrate the work from the entire online research process (using the previously described documents) to create a summary overview of their project that can be shared with a scientific audience. This was the first scientific presentation for our students, so we provided heavily guided prompts, including sentence starters and tips for incorporating information from other remote lab project documents. If your students are more familiar with the content and structure of presentations, you can reduce the prompts.

After finalizing their presentation script, our students recorded and uploaded a Flipgrid video of themselves presenting their project. Flipgrid (flipgrid.com) is a free social learning platform that allows instructors to set up "grids" with a particular prompt (and provide a sample video, if desired). Students easily record videos of themselves presenting their project summary scripts using their phones, tablets, or laptop devices with cameras. Videos can be set to be viewable by instructor only or by the whole course community. If videos are made viewable to all students, you could incorporate a peer review assignment or activate the Flipgrid feature that enables students to post video replies or feedback on one another's videos.

Alternatively, individual students or student groups could be guided to create PowerPoint presentations outlining the experimental plan, analysis, and connection to the literature and present them in synchronous class sessions. Or, you could provide students with a poster template and guide them to use the information from the remote lab documents to complete the poster (Supporting File S6: Remote Learning with Datasets – Research Poster Template). Posters could be shared with you only, shared with the class in a "virtual poster session" through Google Slides, or presented by students in synchronous class sessions.

SCIENTIFIC TEACHING THEMES

Active Learning

In this framework, students are actively engaged stepwise with the scientific research process while completing each guided document. They build scientific skills through hands-on use of graphing and statistical programs. Additionally, students actively record responses in their own words in each assignment document and share their work in writing and verbally through presentations.

Active student engagement with these documents can occur through various modalities. During the COVID-19 response of Spring 2020, our lab was moved to a fully asynchronous online course format, and we assigned all remote lab documents to be completed as independent weekly assignments. In the subsequent semester the lab course was synchronous online, and each document in the set was assigned for collaborative weekly group work in Zoom breakout rooms. To facilitate collaboration, documents were posted to Google docs as "view only" files, and each group created and shared their own set of editable copies to work on together. In both semesters, the assignment sets served as summative assessments of the lab course learning objectives in a form of a culminating project.

As an alternative to a culminating project, these documents could be used as instructional aids about the research process during the course. Instruction could occur in-person or remotely, and students could then complete the relevant document as a formative assessment and a way to reinforce the instruction. With this approach, instructors could use one data set to model and work through as a whole group; then students could select one of the other two datasets to work through independently.

Assessment

Each assignment in this framework serves as a stepwise assessment to identify student gains in particular scientific skills. The documents' guided nature allows you to clearly outline the learning objectives, modify prompts to align with your specific course learning objectives, design grading rubrics to assess student progress toward mastering the skills, and pinpoint areas where each student may be struggling and need feedback and support. A sample grading checklist has been provided in the Data Analysis Document (Supporting File S3: Remote Learning with Datasets-Data Analysis Document).

We recommend spacing assignments to allow for timely feedback before the next assignment is due. Because the assignments build on one another, it is important to give students time to correct any mistakes, omissions, or misconceptions in their work to prevent errors from carrying forward through the whole project. If the goal is for students to experience and gain competency in the entire research process, then it is critical to set expectations for students to master all components while being supported along the way. We used a "mastery" grading approach for these assignments– outlining clear objectives or specifications, requiring all documents to be completed to competency, and allowing resubmissions (with no grade penalty) until the minimum level of competency was achieved or surpassed.

Inclusive Teaching

The scaffolded and highly guided format of this framework navigates students through each step of the scientific process, which is particularly helpful for introductory students (12, 13). Our approach makes expectations clear for each step in the process and allows students to practice, receive feedback, and make changes as they work toward mastering the skills. This stepwise approach encourages a growth mindset and is more supportive than assigning a comprehensive assignment to "write a lab report" and then leave it to students to determine the important steps. By explicitly teaching students these skills in a scaffolded manner, we aim for students to gain awareness of their learning and cultivate their science identities, which may encourage them to confidently and enthusiastically pursue future science coursework (14-16).

In the various assignments there are opportunities to emphasize altruistic applications of science by highlighting ways that the research can be used to improve the planet or society. Additionally, there are opportunities to affirm the collaborative nature of research and the diverse identities of scientists—by asking students to locate information about the authors and/or by choosing literature references written by diverse scientists.

SUPPORTING MATERIALS

- S1. Remote Learning with Datasets - Student Datasets (includes references for relevant, readable research studies)
- S2. Remote Learning with Datasets - Experimental Planning Document
- S3. Remote Learning with Datasets - Data Analysis

Document
- S4. Remote Learning with Datasets - Literature References Document
- S5. Remote Learning with Datasets - Project Summary Script and Presentation Document
- S6. Remote Learning with Datasets – Research Poster Template

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