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Teaching the Bean Beetle Microbiome CURE in an Online Format

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Most course-based undergraduate research experiences (CUREs) are designed as immersive, in-class research activities. The bean beetle microbiome CURE is no different in this regard. However, as a consequence of the COVID-19 pandemic, sudden conversion from face-to-face instruction to hybrid and completely online instruction provided the opportunity to consider how best to teach a CURE online and to determine the aspects of experimentation that can be addressed without in-person instruction. Across four consecutive semesters, one of us (LSB) taught the bean beetle microbiome CURE to first-semester biology majors face-to-face, in hybrid format (face-to-face for half a semester and online for half a semester), and then fully online. This presentation and discussion focused on the process of converting this CURE from in-person to online and considered the aspects of experimentation that can be retained and those that are lost when in an online format. This conversion process, applicable to any CURE, requires careful consideration of critical learning outcomes we seek from laboratory activities, and thus has the capacity to influence how we teach in any format in the future.

Keywords: course-based undergraduate research experiences, online laboratory, biological experimentation

Link To Supplemental Materials: https://doi.org/10.37590/able.v42.sup19

Introduction

The purpose of this mini-workshop was to compare in-person versus online presentation of the course-based undergraduate research experience (CURE) laboratory curriculum developed as part of the Bean Beetle Microbiome Project (https://www.beanbeetle.org/microbiome/curriculum-materials/), also described in Cole et al. (2018) and Zelaya et al. (2020). The abrupt cessation of in-person instruction caused by the COVID-19 pandemic, induced one of us (LSB) to attempt to replicate as much of an authentic research experience as possible in an online format. Syllabi for both in-person and online laboratory courses are presented here with descriptions of the course content similarities and differences.

Instructional Context

The laboratory courses in which these two modes of instruction occurred were the first-semester biology major's lecture and laboratory course at Morehouse College, an historically black (HBCU), private, liberal arts college for men. Most of the students in the course were first-year students and none had previously completed a college-level biology laboratory course. The laboratory constituted 40% of the course grade. The bean beetle microbiome curriculum was implemented in a full-semester format in both in-person and online courses, and one of us (LSB) taught one or two laboratory sections in this course each semester from Fall 2019 to Spring 2021. In Fall 2019, the laboratory sections were taught in-person. In Spring 2020, instruction began in-person but shifted to online after mid-semester. The laboratory was taught as a fully online course in both Fall 2020 and Spring 2021. In all four semesters, the laboratory instructors did not participate in the lecture portion of the course.

Basic Competencies of Biological Experimentation

Pelaez et al. (2016) provide a comprehensive outline of the basic competencies of biological experimentation that may serve as a guide for comparing in-person and online laboratory courses that focus on experimentation (Table 1). There are seven major competencies of biological experimentation that we outline with brief descriptions on how each is addressed in the in-person and online laboratory modalities (Table 1). We are not suggesting that every CURE must address all these basic competencies, but this outline makes it easier to identify components that are similar or different between in-person and online modes of instruction.

Comparing In-person to Online Laboratories

Both in-person and online laboratory formats address all the basic competencies of biological experimentation (Table 1), although in different ways. Here we describe the specific similarities and differences between the in-person and online laboratories through the lens of the basic competencies.

Similarities Between In-person and Online

Whether in-person or online, the bean beetle microbiome CURE begins with students reading some representative studies in the published literature and discussing potential questions to be posed in a new study. In both formats, the instructor guides the discussion on experimental questions to help students, at this introductory level, identify gaps in our current knowledge so the research question that the class pursues will be both authentic and worthy of study. In both instructional formats, students formulate alternative hypotheses to address their research question and plan experiments to be conducted. At first glance, it might seem obvious that online laboratories cannot address the "Conduct" competency (Table 1) since students would not be in the laboratory and are not actually manipulating the biological materials used in an experiment. Yet, in a research study that incorporates both wet lab work and bioinformatics, much of the conduct of research may be accomplished outside a laboratory with a computer and access to the internet (for example, see Huang et al. 2022). Some aspects of data collection are conducted in both formats. For example, bacterial culture plates (in-person) or images of culture plates (online) are evaluated and scored by students to create datasets of bacterial phenotypes that are subsequently analyzed by students using community ecology methods (see Blumer and Beck 2020). In both formats, students choose bacterial colonies for which a portion of the 16S rRNA gene sequence is obtained via Sanger sequencing so bacteria may be identified using NCBI BLAST. In both formats, datasets of identified bacteria may be analyzed by students using community ecology methods (Blumer and Beck 2020). Complete bacterial diversity datasets obtained from 16S rRNA gene MiSeq sequencing of individual bean beetles provide students, in both formats, with massive DNA sequence files that they run through a bioinformatics pipeline to generate bacterial taxonomy data. The taxonomy data from MiSeq sequencing permit students in both formats to again conduct community ecology analyses (Huang et al. 2022). The analyses students in both formats conduct on bacterial phenotypes, Sanger sequences, and Miseq sequences permit them to test their alternative hypotheses and draw conclusions about their research question. Last but not least, students in both formats communicate their findings in the form of written reports and seminar-type presentations.

Differences Between In-person and Online

The differences between online and in-person laboratories are a consequence of students not being in the physical laboratory. Students can see images of bean beetles and videos of live bean beetles, but they cannot actually handle and manipulate them. Students in an online laboratory may view a video showing how bean beetles are

Table 1: Basic Competencies for Biological Experimentation (Pelaez et al. 2016) and Their Inclusion in the Bean Beetle Microbiome CURE Taught in Different Modalities

Competencies	In-Person	Online
"The ability to identify gaps or limitations in current research knowledge through the review, filtering and synthesis of relevant literature."	Students read 2 published research articles, complete worksheets reviewing the articles, and discuss the research in class to identify gaps in current knowledge	Same activity as in-person laboratory
"The ability to generate a research question and formulate hypotheses."	Instructor guides students to generate a consensus research question and then alternative hypotheses and predictions	Same activity as in-person laboratory
"The ability to plan feasible and ethical experiments to answer research questions or test hypotheses."	Instructor leads discussion on experimental design to address the research question	Students complete an online tutorial on experimental design prior to discussion about designing experiment as in-person
"The ability to conduct an investigation to achieve research goals."	Students manipulate biological materials to conduct experiment and collect data	Students evaluate biological materials prepared by instructor to collect data
"The ability to analyze and process data."	Students analyze and process data from all aspects of the research study	Same activity as in-person laboratory
"The ability to conclude about data with inferences that are limited to the scope inherent in the experimental design."	Instructor leads discussion on interpreting results and limitations on reaching conclusions to address research question	Same activity as in-person laboratory
"The ability to communicate research work in professionally appropriate modes, including visual, written, and oral formats."	Students prepare a written report and present a research seminar on their findings	Same activity as in-person laboratory

surface sterilized in preparation for subsequent extraction of the microbiome bacteria (or extraction and purification of DNA), but they cannot actually conduct those procedures. Students in an online laboratory cannot prepare bacterial colonies by micropipetting and spreading extracted microbiome bacteria on culture plates, and they cannot practice aseptic techniques. Online students may indicate a bacterial colony to be picked, but they cannot physically pick the colony, conduct PCR and then perform electrophoresis on the amplified PCR products prior to samples being sent for Sanger sequencing. However, students in the online format did observe transilluminator images of electrophoresis gels showing the results of PCR on bacterial colonies they chose for amplification. Students in an online laboratory cannot use a DNA extraction kit to isolate and purify DNA from individual beetles to be sent out for MiSeq sequencing. However, online laboratory students may view a video demonstrating the DNA extraction and purification process.

Student Outcomes

Summative Outcomes

The median lecture score of students in the course (lecture was taught independently of the laboratory), the course pass rates (ABC final grades) and the course withdrawal rates were tabulated in all four semesters Fall 2019-Spring 2021. We looked at the lecture scores as a means of assessing student performance independent of their performance in the laboratory part of the course.

These metrics did not change appreciably from in-person to hybrid to fully online laboratory modalities (Table 2). The withdrawal rates dramatically increased in the two semesters in which fully online laboratories were conducted, but it is unclear whether that change can be attributed to the change in laboratory modality or the fact that all instruction (laboratory and lecture) was online in those semesters. Admittedly with such a small sample these results are anecdotal but there was no obvious negative effect on student performance in the context of this introductory course resulting from teaching laboratories online. That is not to totally discount the value of hands-on laboratory experience however, an online laboratory can replicate many of the basic competencies of biological experimentation that would occur in an in-person laboratory.

Focus Group Themes

Virtual focus groups were conducted by one of us (SNY), without the laboratory instructor present, in each of the four semesters from Fall 2019 – Spring 2021. The focus group facilitator used a semi-structured approach. Students were queried about their experiences in the course with particular interest in experiences that might influence their development of a science identity. The themes that emerged from the focus groups (Table 3) were very similar in the in-person, hybrid and online format laboratories. There were no strong effects of the online format on students' sense of conducting authentic research nor on their expression of the biological experimentation process.

Table 2: Effect of Course Format on Student Outcomes

Semester	Course Format	Number of Student	Median Lecture Score	Pass Rate	Withdrawal Rate
Fall 2019	In-person	75	71.0%	72.0%	5.0%
Spring 2020	Hybrid	31	78.0%	77.4%	0.0%
Fall 2020	Online	72	82.5%	81.9%	15.5%
Spring 2021	Online	22	75.0%	81.8%	16.0%

Table 3: Focus Group Themes

Definition of a scientist
- Different types of scientists
- Someone who advances knowledge
- Scientific method
- Student as a scientists
- Data analysis
- Laboratory techniques
- Writing and reporting results
- Hypothesis testing

Application of course content
Contributing to the scientific community
Data literacy
General knowledge
Interdisciplinarity
Role of misinformation
Role of professor
Trust
Workload
Advantages of virtual learning
Disadvantages of virtual learning
Hands-on learning

Student Course Syllabi

The complete syllabi for the in-person laboratory courses taught in Fall 2019 and the fully online laboratory course taught in Spring 2021 are included as supplemental materials. On both syllabi, content that is unique to each modality is highlighted.

Materials

Details on the bean beetle microbiome CURE may be found at: www.beanbeetles.org

Notes for the Instructor

The laboratory preparation instructions and detailed protocols are the same in both in-person and online formats but here we briefly describe the work that was performed by the instructor in the online format that would have been conducted by students in an in-person format.

Bacterial Culturing

The instructor surface sterilized four individual bean beetles from each of two treatment groups for each laboratory class (eight beetles). The instructor then prepared a microbiome extract from each beetle and made four culture plates using each extract (see www.beanbeetles.org for the culture media used). A class set consisted of 32 culture plates plus two negative control cultures. In both semesters, one treatment group was the same in each of two laboratory sections that were taught in the same semester, so a total of 48 culture were prepared by the instructor plus two negative controls for two laboratory sections. After incubating plates for 24 - 48 hours, each plate was photographed and the images were posted online for student access. Culture plates were assigned to individual students to score.

Picked Colony PCR and Electrophoresis

Students selected a colony to be picked but the instructor actually picked one bacterial colony for each student, prepared a bacterial dilution of that colony and performed PCR on that bacterial colony for the 16S V4 region of the rRNA gene. One preparation was made for each student in the class as well as one positive and one negative control. Following PCR, the instructor poured agarose gels and performed electrophoresis of every sample along with a positive and negative control and a DNA ladder. One gel was run for every five students in the laboratory course, so a class of 20 would require four gels. The results of each electrophoresis run were photographed on a transilluminator by the instructor, and text boxes were added to the images to add gel lane identification labels prior to posting online for student access.

DNA Extraction for NGS

The instructor surface sterilized ten individual bean beetles from each of two treatment groups for each laboratory class (20 beetles). The instructor performed DNA extraction on each individual beetle so the DNA could be sent for NextGen sequencing of the 16S V4 region of the rRNA gene in the microbiome bacteria. DNA extraction was performed in batches of 5-6 samples per batch. One negative control also was extracted for each class. In both semesters, one treatment group was the same in each of two laboratory sections that were taught in the same semester so a total of 30 DNA extractions were performed on beetles.

Using Data from Prior Semesters

It is possible to use previously collected data rather than having to perform the bacterial culturing, colony PCR and electrophoresis, and DNA extraction for each class in every semester. However, using previously collected data requires that the instructor set the research question. The importance of giving students autonomy in choosing the research question is the focus of our current research. It is not clear what or how much student learning gains would be lost by taking that autonomy away from students.

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Appendix A

A pdf document of the In-person Syllabus used in the Fall 2019 laboratory will be linked here.

Appendix B

A pdf document of the Online Syllabus used in the Spring 2021 laboratory will be linked here.

Appendix C

A pdf document of the PowerPoint slides from the mini-workshop presentation will be linked here.

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The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with teaching biology in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit http://www.ableweb.org/.

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