# Effect of Changes in Course Delivery Format in Response to the COVID-19 Pandemic on Self-Assessed Learning Gains in a Large Introductory Biology CURE

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## Abstract

The COVID-19 pandemic presented many challenges for educators. In Course-based Undergraduate Research Experiences (CUREs), where students learn about the scientific process by working on novel research, few resources for remote learning were available. Here the impact of changes to course delivery format on student learning gains in a large-enrollment introductory biology laboratory CURE was assessed during Fall 2019 pre-COVID-19, a fully in-person CURE; Spring 2020 COVID interruption, where half of the semester was fully in-person and half was fully remote instruction; and Fall 2020 fully COVID-impacted, where the CURE followed a hybrid format (alternating between in-person one week and remote the next week). Remote course delivery was achieved using video conferencing software for remote laboratories and pre-recorded videos for lecture. Analyses of the results from pre- and post-surveys and the Laboratory Course Assessment Survey (LCAS) verified that a structured remote process that utilizes collaborative software embedded into a hybrid lab format was equivalent in student self-reported gains to the fully in-person mode. Thus, with assistance from remote software for certain activities, it is possible to conduct large-enrollment CUREs despite major disruption such as COVID-19 precautions related to social distancing and therefore CURE need not be abandoned in situations that necessitate alternative modes of instruction.

**Keywords:** *CURE, Course-based Undergraduate Research Experience, COVID-19, pandemic, Equivalency Theory, introductory biology laboratory, course delivery format, remote, hybrid*

## Introduction

Providing students with equivalent learning experiences across educational formats is the central tenant of Equivalency Theory (Simonson et al., 1999). Equivalency Theory developed during the digital age and has frequently been applied when examining approaches to remote learning. Many studies have attempted to determine whether remote instruction is as effective as traditional in-person course delivery. In a 2010 meta-analysis, the U.S. Department of Education concluded that students in remote settings performed at least as well as those students in traditional in-person classrooms. More recent findings put this conclusion in doubt however, as current research has found that outcomes associated with remote instruction can vary based on student background and course design factors (such as learning community structure, remote activity types, and active engagement level), and that the true effectiveness of traditional learning compared to remote could be masked by selection bias (Nguyen, 2015). Additionally, many of the studies included in these analyses have focused on comparing outcomes in lecture-based courses, so less is known about equivalency in remote versus in-person laboratory courses.

Some research on instructional labs has shown no difference in outcomes between remote versus traditional delivery formats (Ogot et al., 2003; Ayega & Khan, 2020). However, these studies investigated individual lab modules, such as the use of remote controls for laboratory experiments or virtual simulations for biology laboratory exercises. In contrast, Son et al. (2016) found that students in the hybrid delivery format (alternating a week in lab and a week remote) of a general education biology lab had significantly better grades and better attitudes towards biology when compared to students in a fully in-person and a fully remote version of the course. These findings align with research done in a microbiology lab course showing that students have a strong preference for at least a portion of their lab courses to include an in-person component (Brockman et al., 2020). The recent global shift to remote learning in response to the COVID-19 pandemic created a unique situation for building our limited understanding of the effectiveness of remote instruction in laboratory courses. Additionally, since students were transitioned to remote learning environments without choice, selection bias may be limited in these datasets. This report investigates the impact of changes to course delivery format in response to the pandemic on student learning gains in a large-enrollment introductory biology laboratory Course-based Undergraduate Research Experience (CURE).

Increasingly CURE is being used to replace traditional "cookbook" laboratory courses in the sciences (Dolan, 2016). The primary objectives of CURE are to help students understand the process of science and to give them a sense of what being a scientist entails. The five areas that define a CURE include: (1) use of scientific practices, (2) collaboration, (3) iteration, (4) discovery-based, and (5) broadly relevant and/or important work (Auchincloss et al., 2014; Brownell & Kloser, 2015). Typically, there are specific considerations in developing CUREs, such as that students learn some wet lab techniques, how to collect data, how to design and conduct experiments, and how to trouble-shoot problems that arise in a particular discipline. Compared to online modules or remote simulation activities that follow the "cookbook" approach to laboratory instruction, there are significant challenges maintaining equivalency when developing remote CUREs that must incorporate these important elements.

Due to COVID-19, switching mid-term in Spring 2020 from a large enrollment, in-person wet lab CURE to entirely remote with just a week's notice was daunting. For the subsequent term, Fall 2020, it was necessary to create a new version of the CURE, in which the students had alternate weeks of in-person and remote labs, to ensure that lab sessions were at half capacity for social distancing. This article describes the effort to meet CURE objectives while maintaining the course research theme across the different versions and varying delivery formats. It also takes a quantitative approach to examine impacts on students' self-reported learning gains and their perceptions on participating in the defining features of CURE across three consecutive semesters: Fall 2019 (F19), pre-COVID, where the course was fully in-person; Spring 2020 (S20), COVID interruption, where the course was fully in-person for first half of the semester and fully remote for the second half, and Fall 2020 (F20), fully COVID-impacted, where the course was hybrid (alternate weeks of in-person and remote labs).

## Background

### *1. Basic CURE Course Structure*

At Binghamton University, Introductory Biology Lab (BIOL 115) is a 2-credit stand-alone CURE that incorporates aspects of structured and open CURE inquiry (see Table 1 from Brownell & Kloser, 2015). The research theme focuses on gradients of anthropogenic disturbance and uses molecular and ecological techniques to address questions related to global change biology. Each 14-week term, the course has about 400 undergraduates, largely composed of first-year and second-year biology majors. The course has 18 lab sections, and each section has 24 students supervised by a graduate teaching assistant (TA) and one or two undergraduate peer mentors (UGPM).

Specifically, students partake in a novel research project where the course research questions, theoretical background, and some methods are predetermined but where the answers to the research questions are unknown and the students have flexibility in their analysis and conclusions. Each week, students attend a three-hour lab and a one-hour lecture that reinforces CURE via providing background on the research theme and skill development (e.g., how to read primary literature, make well-designed figures and legends, perform and interpret statistical analyses, and write a research report). Typically, the in-person lecture utilizes a variety of active-learning approaches to increase student engagement and understanding including clicker-type questions, think/pair/shares, graph reading and interpretation, research team discussion, and others (Freeman et al., 2014). In lecture, students are also required to sit with and discuss with their teams the questions posed by these formative assessments so as to also further develop communication and group problem-solving skills.

The lab portion begins with four weeks where students learn about sampling, how to use equipment (e.g., electrical conductivity probes) and follow protocols (e.g., extracting DNA from soil). They practice using basic spreadsheet functions, calculating statistics, and creating appropriate graphs. At the beginning of the course, students are assigned to a team (four per team) and use the first four weeks to build their teamwork skills. In the fifth week, with the course research question in mind, teams draft a 1-2 page proposal outlining their research design (including research hypotheses justified through the literature, proposed methods, data collection protocols, and data analysis). Over the next five weeks, teams work on their research projects, generating data, and doing analyses. The last few weeks of the course focus on teams preparing and then sharing, via a public poster presentation, their findings and outlining what they would do next or a related future research project.

Course assessment includes a pre- and post-survey of self-reported research methods skills (Reeves et al., 2018) and the Laboratory Course Assessment Survey (LCAS, Corwin et al., 2015; Corwin et al., 2018). Slight modifications were made to the pre- and post-survey including removing four statements that were specific to the research done in the CURE described by Reeves et al. (2018) and replacing those with four new statements that better reflected the research done in BIOL115 (Supplemental Table 1). Both assessments were consistent in all three semesters described in this manuscript.

In addition to the background needed for the research focus and skills, a major element of the course addresses professionalization by emphasis on communication, teamwork, project management, shared leadership, and an array of technical skills. The teamwork element of the course is guided by the course instructor, TAs, and Undergraduate Peer Mentors (UGPMs). Students fill out team contracts on day one of the course that emphasize communication, identifying individual strengths and weaknesses, and planning ahead (Davis & Ulseth, 2013; Wolfe, 2010). They are also given guidelines to develop their teamwork and collaborative skills. Throughout the term that is reinforced, for example, with team meetings facilitated by TAs and UGPMs, where a team can discuss challenges, reflect on team dynamics, and trouble-shoot. A remote evaluation tool is also used (Layton et al, 2010) which creates a digital report of student ratings and comments on teamwork. This report is reviewed by each team member, the course instructor, TAs, and UGPMs. Individually students present "elevator talks" (one minute describing their research project to non-scientist audience, Bowen, 2006), and student teams create a formal science-conference-style poster, a final written research report in journal format, and a PowerPoint presentation that outlines their proposed follow up or future research project.

### 2. *Fully in-person CURE, Pre COVID-19 - Fall 2019*

This CURE focused on assessing the impact of the removal of overabundant deer on forest soil microbial community function and composition relative to soil characteristics at six different deer exclosure sites (i.e., areas where deer are fenced out) in the campus Nature Preserve that were being studied by others in terms of effects on plant growth and diversity. For the first four weeks, the lab sections focused on the course modules designed to introduce the students to the overall research theme, the technical skills (lab protocols, digital spreadsheets, basic statistics, graphing and so forth) they needed to develop before executing the course research project and to lay a foundation for the other professional skills (communication, teamwork, project management, and shared leadership). Due to the logistical limitations in getting 400 students out in the field and into six fenced exclosure units, the sites were sampled by the course instructor, MA Kearney. Each lab section of 24 students had six research teams, and each research team was assigned via lottery system an exclosure site for their project (but no replications within a lab section of the site possibilities), with a total of 18 lab sections, each site was replicated 18 times.

In week five, student teams drafted 1-2 page proposals outlining their research design (including the predetermined research questions and research hypothesis justified through the literature, details on the suggested methods, data collection protocols, and data analysis). In week six, groups began their research project starting with extracting DNA from their soil samples. Given equipment and time constraints, the course instructor typically sequences previously extracted DNA via use of a minION portable sequencer, followed by the automated assignment of OTUs via MG-RAST. Following this procedure, students were thus provided, in week seven, with an MS excel spreadsheet containing all of the microbial taxonomic data from the sequenced DNA. Student teams also in week 7 measured soil function (respiration) and soil characteristics (pH and conductivity values) and entered these data into a large class database (Google Sheets, Google LLC., 2021) by site and all teams were provided with this full dataset, allowing them to work with a more robust sample size for analysis.

Over the next six weeks of the semester, teams analyzed their results in the context of the original predefined questions using the skills and knowledge from the practice activities and lecture topics (e.g., statistics) covered in the first part of the semester. Based on their findings they drafted a manuscript in scientific format and produced and presented scientific conference-style posters in the penultimate week. In the final week of the lab, based on their findings from the research project, teams discussed their ideas for future research projects and each team gave a final presentation where they explored a proposed follow-up study.

### 3. *Half in-person and half remote CURE, COVID-19 interruption- Spring 2020*

In S20, the course focused on assessing the impact of a wide-spread invasive plant, Japanese knotweed (*Polygonum cuspidatum*), on soil microbial community function and composition relative to soil characteristics at six different sites. As in F19, for the first four weeks, the lab sections focused on completing the course modules before executing the research project. Again, due to the logistical limitations in getting 400 students out in the field, especially in January with frozen soil, the sites were sampled by the TAs and UGPMs under the supervision and direction of the course instructor. As in the F19 semester, each lab section of 24 students had six research teams, and each research team was assigned via lottery system a site for their project. Although again with no replications within a lab section of the site possibilities, across lab sections each site was replicated 18 times.

In response to the COVID-19 pandemic, in mid-March 2020, the university abruptly switched from in-person to entirely remote delivery. At the point of transition, the students had had seven weeks of in-person lab and lecture in parallel to the F19 course. The students were also able to conduct lab protocols and function as teams, and they had already completed some data collection for their research project (six sites with 18 replicates).

### *3.1 Major changes in lecture*

In response to the transition to remote delivery, pre-recorded videos were created for each of the remaining lectures. This posed a challenge from an engagement and teamwork standpoint. With the rapid transition of both lecture and lab material to remote and the logistics of adapting to a remote environment, the videos produced largely lacked active learning elements and were simply uploaded to YouTube once per week with links and email announcements about them posted and sent through the university's learning management system, Blackboard. The content of these lectures remained the same as in F19.

### 3.2 Major changes in lab

By week seven, students had begun their research project and had extracted DNA from their soil samples. As in the fall, the course instructor had in the previous week already sequenced extracted DNA from the soil samples and thus provided all student teams with the MS excel spreadsheet containing all of the microbial taxonomic data the week after the in-person shutdown. Also, the week before, in anticipation of the switch to remote instruction, the course instructor along with the TAs and UGPMs, collected some data on soil function (respiration) and characteristics (pH and conductivity values). These data were provided to the students for analysis, but students did not have the opportunity to collect the data themselves and enter it into the class database spreadsheet.

After the switch to remote, the three-hour lab sections were conducted live through Zoom during the same scheduled time periods. TAs and UGPMs were given rapid training in the use of Zoom with a particular emphasis on the breakout room feature. The remainder of the semester, students were guided through data analysis, how to construct scientific posters, and communicate findings through virtual labs held on Zoom. They utilized G Suite (Google LLC., 2021) tools to cooperatively work on their analyses and assignments (e.g., research paper and posters). The team presentations, including the scientific poster presentation and the future research/follow-up study presentation were presented via Zoom to TA and UGPMs in the individual breakout rooms using the share screen feature (Table 1).

| CURE Element | Software Tools |
|---|---|
| (1) Uses scientific practices | *Asking questions and building and evaluating models*<br>• **Zoom whiteboard** feature used in virtual team **breakout rooms** to sketch out ideas conceptually<br>*Using the tools of science & gathering and analyzing data*<br>• **Zoom share screen** feature in virtual **breakout rooms** to collaborate on results<br>○ **PAST (PAleontological STatistics)**[1]- statistical analysis<br>○ **IMAGEJ/FIJI**[2]- data analysis (F20)<br>○ **Plot.ly Chart Studios**[3]- online graphing program (F20)<br>• **Google Sheets**[4] for entering and sharing data<br>• **MS Excel** spreadsheets for data organization and analysis<br>*Communicating findings*<br>• **Zoom share screen** feature used in **main virtual lab room** paired with **Google Slides**[4] |
| (2) Collaboration | *Participate in research as a team*<br>• **CATME SMARTER Teamwork** online teamwork survey system with feedback for optimizing team dynamics (Layton et al,. 2010)<br>*Work together to develop, execute, share research project*<br>• **Zoom virtual breakout rooms with preassigned** research teams paired with<br>○ **Google Drive**[4] for storing and collaboratively filling out team documents including team contract<br>○ **G suite** for working collaboratively on team assignments (**Google Docs**[4] and **Google Slides**[4]) and monitoring contributions of each student |
| (3) Iteration | *Design, conduct, and interpret an investigation and, based on results, repeat or revise aspects of work to address problems or inconsistencies, rule out alternative explanations, or gather additional data to support assertions*<br>• **Zoom virtual breakout rooms with preassigned** research teams paired with<br>○ **G suite** for working collaboratively with team on future/follow up research proposal presentation (**Google Docs**[4] and **Google Slides**[4])<br>○ **Zoom share screen** feature used in **main virtual lab room** paired with **Google Slides**[4] to present to full lab class |
| (4) Discovery-based | *Consider the work of their peers collectively and findings offer new insight into how the natural world works*<br>• **Google Sheets**[4] for sharing data from the broader class research project (all of the data from replicated mini projects across the 18 lab sections in one organized location). |
| (5) Broadly relevant and/or important work | *Work on a research project that fits into a broader scientific endeavor that has meaning beyond the particular course context.*<br>• **Google Forms**[4] for students to submit raw images and data from the research project |
| | • **Google Drive**[4] for archiving all data, student team reports, and relevant literature |

[1]PAleontological STatistics Version 3.26 (Hammer et al., 2001)

[2]Schindelin et al. (2012)

[3]Plotly Chart Studios (Plotly Technologies Inc. https://plotly.com)

[4]Google LLC., 2021

**Table 1. Essential software tools used to support BIOL 115, Introductory Biology Lab CURE. Italicized phrases are modified from Auchincloss et al. (2014).**

## 4. Hybrid CURE, COVID-19 fully impacted-Fall 2020

In response to the ongoing pandemic and realizing the best option might not be known until the fall term began, the university instructed faculty to plan F20 for both an entirely remote version and a hybrid version that would allow some degree of in-person participation. A hybrid model was necessary to implement COVID-19 precautions specifically, social distancing (i.e., all classrooms would be capped at half capacity). Under a hybrid format, students would be in-person in the lab session one week, followed by remote for the lab session the following week. It was determined that the implementation of the usual course research project would be impossible in either an entirely remote or hybrid format, thus, the course underwent a complete redesign that required key changes to keep aligned with the original course format of a combination of structured and open CURE inquiry.

While the overall research theme remained the same, a new research project needed to have two key features. First, it had to be possible to conduct the research successfully in the hybrid model, when the students were only in the lab every other week, as in-person would alternate with a week of remote instruction. In addition, the research would have to be amenable to possible abrupt transition to fully remote. For example, what if there were only two weeks of hybrid, then a switch to entirely remote? Second, research protocols had to be simple enough to initiate with little practice and training, such that the research could be started immediately to ensure that students would be able to complete enough data acquisition to have something reasonable to analyze for the course.

The fall course began with a hybrid approach to the labs and a fully remote lecture. Sticking with the general theme of anthropogenic disturbance and global change biology, the fall course research focused on impacts of common ecotox contaminants (household pesticides and salt, NaCl, which is a road-runoff issue in local watersheds due to snow-ice road treatment) on seedling survival and root structure. To visualize root-structure, students followed a modified protocol from Cassidy et al. (2020), where standard CD-jewel cases served as rhizotrons to grow lettuce (*Lactuca sativa*) seedlings over a five-week period, during which student teams treated their rhizotrons with experimental ecotox solutions. In weeks where students were remote during the experiment period, TAs and UGPMs applied these treatments for them. Consistent with the F19 and S20 semesters, each lab section had six research teams (each with four students), and teams were assigned via lottery one of six possible mini projects (Table 2), with these same six projects repeated across all 18 lab sections.

Thus, the first key feature of flexibility was met as (a) replication across the lab sections allowed students to be able to make mistakes and still have analyzable data, and (b) the supplies needed to execute the new research project were relatively cheap and could be given to students as "kits" to complete research at home in the event of a possible transition to fully remote in response to COVID-19 dynamics. The project was also relatively simple methodologically, meeting the second key feature, and therefore was able to be executed rapidly as it did not require practice and mastery of complex protocols before initiating.

### 4.1 Major changes in lecture

Due to the large course size (400 students in F20), each week asynchronous pre-recorded videos were utilized and posted on YouTube as the primary format for lectures. To increase student engagement with the lecture video content, each video was embedded with multiple active-learning style questions. Roughly six to eight questions per lecture were spread out across the full length of the video (typically around 30-40 minutes). Each video was released simultaneously with a companion lecture assignment, a Google Form containing each of the video's questions in the order that they appear in the video. Each week, students were expected to watch the video and complete the corresponding lecture assignment for which they received participation points.

### 4.2 Major changes in lab

The tasks that students worked on while in-person in lab included the physical setup of the experiment and planting of the rhizotrons, the application of the treatment solutions, and data collection in week two and at the end of the experiment in week five; all other aspects of the research project were shifted to remote using Zoom and the breakout rooms for group work. Online, students practiced and trained in the use of the software for data organization (Google Sheets, MS Excel) and data analysis (PAST- PAleontological STatistics (Hammer et al., 2001), ImageJ/FIJI (Schindelin et al., 2012), Plot.ly- chart studios (Plotly Technologies Inc. https://plotly.com)) (Table 1). Each activity that was done in the remote weeks prior to the end of the experiment, focused on the development of different skills related to the actual research project. To that end, the first activity centered on a hypothetical research project and subsequent activities then built upon that same hypothetical for each consecutive training activity module. For example, in practice activity #1, student teams used ImageJ/FIJI to measure root characteristics and MS Excel to record data, and in practice activity #2, they used that sample data to practice making relevant graphs in MS Excel and plot.ly, and so on. Thus, student teams were able to practice using software relevant to their project and framing their analyses. They also were able to practice using the collaborative tools in G Suite (Google LLC., 2021), which were later employed by the students when they worked together on their research papers, scientific posters, and future research presentations.

## Methods

### Data Collection

#### Pre- & Post- survey of research skills

In all three semesters, a pre- and post-survey of self-reported research methods skills (Reeves et al., 2018) was administered to students through the course learning management system, Blackboard. The pre-survey was made available to all students through the first two weeks of classes and the post-survey was made available to students a week before the final class of the semester and remained open through finals week (which gave students approximately 2 weeks to complete the post-survey). Student responses to both surveys were fully anonymous but students received two points for completing each survey. All student responses for the pre-survey and post-survey were downloaded into separate MS excel spreadsheets and for each of the 23 statements related to research methods skills answers were coded using a five-point scale range from "strongly disagree" (coded 1) to "strongly agree" (coded 5).

PAST software (PAleontological STatistics, version 4.03) was used for all statistical analyses. Responses for each of the 23 statements on the pre- and post-survey, were coded with scores ranging from 1 (strongly disagree) to 5 (strongly agree). From these values, a mean response score was calculated for each statement (F19 Pre N=390, Post N=372; S20 Pre N=347, Post N=317; F20 Pre N= 346, Post N= 372). To characterize improvement across the class, the average normalized gain (g) for each statement was calculated using the following formula where brackets indicate class averages (Hake, 1998):

$$[g] = \frac{[post] - [pre]}{5 - [pre]}$$

To compare whether the average normalized gains were different across the three semesters an ANOVA with Tukey's pairwise comparisons was calculated. To determine whether the mean pre- survey responses differed across semesters and mean post- survey responses dif-

| | Control | Pesticide | Salt | Mixed |
|---|---|---|---|---|
| 1 | DI Water | Malathion | Slightly Saline 1dS/m NaCl | Malathion & 1dS/m NaCl |
| 2 | DI Water | Malathion | Strongly Saline 6dS/m | Malathion & 6dS/m NaCl |
| 3 | DI Water | Imidacloprid | Slightly Saline 1dS/m NaCl | Imidacloprid & 1dS/m NaCl |
| 4 | DI Water | Imidacloprid | Strongly Saline 6dS/m | Imidacloprid & 6dS/m NaCl |
| 5 | DI Water | Cyfluthrin | Slightly Saline 1dS/m NaCl | Cyfluthrin & 1dS/m NaCl |
| 6 | DI Water | Cyfluthrin | Strongly Saline 6dS/m | Cyfluthrin & 6dS/m NaCl |

**Table 2. Mini project options for the F20 research project. Each of the six student teams in a lab section worked on a different mini project (1-6) and this was repeated across all lab sections.**

fered across semesters, ANOVA with Tukey's pairwise comparisons was also used. To explore whether gains based on the type of research skill were similar or variable across semesters, each statement was classified into one of seven categories related to the research process. Four categories that were identified as substantive factors in a common factor analysis done by (Reeves et al., 2018) were used: experimental design (four statements), written communication (two statements), oral communication (four statements), and collaboration (four statements). The remaining statements were classified by this author based on the content of the statement and which research skill area the statement addressed. The three categories were: literature skills (three statements), visual communication (one statement), and data analysis (five statements) (Supplemental Table 1). The normalized learning gains for each statement were sorted from greatest gain to least gain for each semester and the research skill category for the top eight statements (approximately one third of the total statements) for each semester were compared.

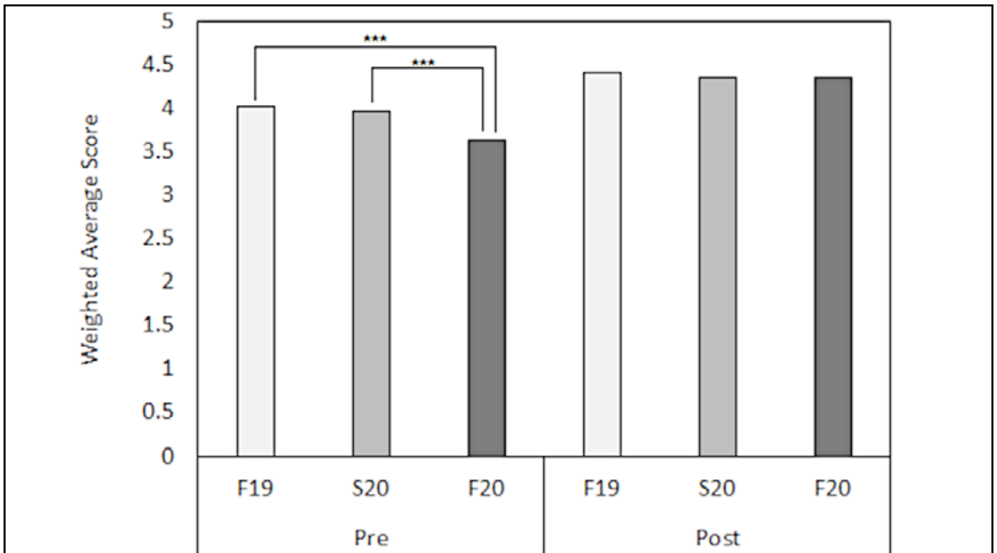


**Figure 1.** **Weighted average pre-survey and post-survey scores by semester of BIOL 115 (F19- light gray, S20- medium gray, and F20- dark gray). Columns marked with *** were significantly different from one another based on Tukey's pairwise comparisons (p < 0.001).**

### Laboratory Course Assessment Survey (LCAS)

The Laboratory Course Assessment Survey (LCAS, Corwin et al., 2015) measures student perceptions of three design features of biology lab courses: *collaboration*, relevant discovery, and iteration and compares them to a national reference dataset from a traditional lab course and a CURE. The survey prompts students to rate their level of agreement with statements about the three design features, including six statements related to encouragement of collaboration (options for responses that included "weekly", "biweekly", "monthly", "one or two times", and "never"); five statements related to expectations for engaging in *relevant discovery* (six response options ranging from "strongly disagree" to "strongly agree"); and six statements related to time to do *iterative* work (six response options ranging from "strongly disagree" to "strongly agree").

In all three semesters, the LCAS was administered to students through the course learning management system, Blackboard, and was made available to students a week before the final class of the semester and remained open through finals week (which gave students approximately 2 weeks to complete the post-survey). Student responses to the survey were fully anonymous but students received two points for completing each survey. All student responses were downloaded to a MS excel spreadsheet and responses to prompts were coded as follows: collaboration (0 "never" to 4 "weekly"); relevant discovery (1 "strongly disagree" to 6 "strongly agree"); and iterative work (1 "strongly disagree" to 6 "strongly agree"). Students who left responses blank or chose prompts "I don't know", "I prefer not to answer", or "no response" were removed from the analysis of that design feature. Individual student totals for each design feature were calculated by adding up the total number from the coded responses for each prompt associated with that feature. A total LCAS score was also calculated by adding up the total scores for each design feature for every student who provided a codable response for all prompts in the full survey. Mean scores for each design feature (*collaboration*: F19 N= 314, S20 N=266, F20 N= 299; *relevant discovery:* F19 N= 355, S20 N=290, F20 N= 345; *iterative work:* F19 N= 341, S20 N=280, F20 N= 332) and the LCAS total were also calculated (F19 N= 281, S20 N=224, F20 N= 253). A value for "percent of range possible" was calculated by determining the percent of the total points possible that were represented by the mean score. For comparisons, these percentages were graphed alongside the percent range possible data from the national reference dataset from a traditional lab course and a CURE (Corwin et al., 2015).

## Results and Discussion

### *Pre- and Post-survey of research skills*

Normalized learning gains increased on average by 0.41, 0.39, and 0.56 points for F19, S20, and F20, respectively. The normalized gains were significantly different (ANOVA, p<0.001) with students in F20 having significantly higher learning gains compared to students in F19 and S20 (Tukey's pairwise, p<0.001 for both comparisons) while learning gains in F19 and S20 were not different from one another (Tukey's pairwise, p= 0.52).

Further analysis comparing the average pre-survey scores by semester revealed a significant difference (ANOVA, p<0.001). Interestingly, between F19 and S20 there was no difference in self-assessment of research skills prior to the start of the course (Tukey's pairwise comparisons, p=0.62) but students one semester later, in F20, rated themselves significantly lower in their self-assessment of research skills in the pre-survey compared to F19 and S20 (Tukey's pairwise comparisons, p < 0.001 for both, Fig. 1). However, there was no difference in average post-survey scores across all 3 semesters (ANOVA, p=0.39, Fig. 1), indicating that by the end of each semester, regardless of the course delivery format, students' self-reported gains were similar.

Together, these findings explain the significantly higher normalized learning gains in F20. Since students rated themselves significantly lower in their skill levels prior to the start of the course in F20 compared to F19 and S20, while reporting similar learning gains to F19 and S20 by the end of the course, normalized differences between pre-survey and post-survey scores were higher in F20. The lower pre-survey scores in F20 suggest that either (1) students in this semester began the semester at a lower experience level than in previous semesters (yet finished the semester at the same level as pre-pandemic students) or (2) students felt less confident in their abilities beginning the semester compared to previous cohorts pre-pandemic.

The research skill categories for which students showed the highest normalized learning gains (the top eight statements, approximately one third of all statements) were similar across the three semesters (Table 3). Collaboration statements in all three semesters were the most represented skill category (three in F19, two in S20, and four in F20), thus students' largest gains came in development of strong teamwork skills regardless of course delivery format. They also similarly made the highest gains in oral communication, experimental design, literature skills, and visual communication, all categories that showed up at least once in the top eight statements (Table 3).

### Laboratory Course Assessment Survey (LCAS)

In reference to the published CURE dataset (Corwin et al., 2015), BIOL 115 as CURE exhibited similar patterns (Fig. 2). When comparing the three semesters of BIOL 115

| Research Skill Category | F19 | S20 | F20 |
|---|---|---|---|
| Collaboration | 3 | 2 | 4 |
| Oral Communication | 2 | 1 | 1 |
| Experimental Design | 1 | 2 | 1 |
| Literature Skills | 1 | 2 | 1 |
| Visual Communication | 1 | 1 | 1 |
| Written Communication | - | - | - |
| Data Analysis | - | - | - |

**Table 3. Semester comparison of the number of statements by research skill category that had the great est normalized learning gains. Students reported gains in all 23 statements (Supplemental Table 1), here the skill categories for the top eight are reported. Statements related to the written communication and data analysis skill categories were not among the eight statements with the greatest reported learning gains.**

(F19, S20, and F20), there was a noticeable dip in student perceptions related to course discovery and iteration in S20, the COVID-interrupted semester. Most likely that reflects the abrupt transition of the course to a fully remote format. Students were only able to complete a small portion of their research project themselves and even though they were provided with the final data for analysis, they missed the normal interim stages of the previously planned course, which would have reinforced "discovery" and "iteration" elements. This result helped to shape the research project for F20 under the unknown dynamics of COVID-19. Given that students were likely to experience scientific discovery and iteration better when setting up and running an experiment themselves compared to, for example, working with previously collected data, it was important to try to maintain a hands-on approach. Thus, during planning this author endeavored to design a research project that would incorporate flexibility and simplicity. However, even with the lower perceptions of discovery and iteration in S20, that CURE still performed well compared with the traditional lab courses. Interestingly, the high rating for collaboration in the COVID-interrupted semester may be attributable to the prevailing "we're all in this together" sentiment that was particularly acute during the early phase of the pandemic.

## Conclusion

This research shows that equivalency in CURE laboratory courses is achievable. The large enrollment introductory biology CURE reported on here underwent major changes in delivery format (from in-person, to half in-

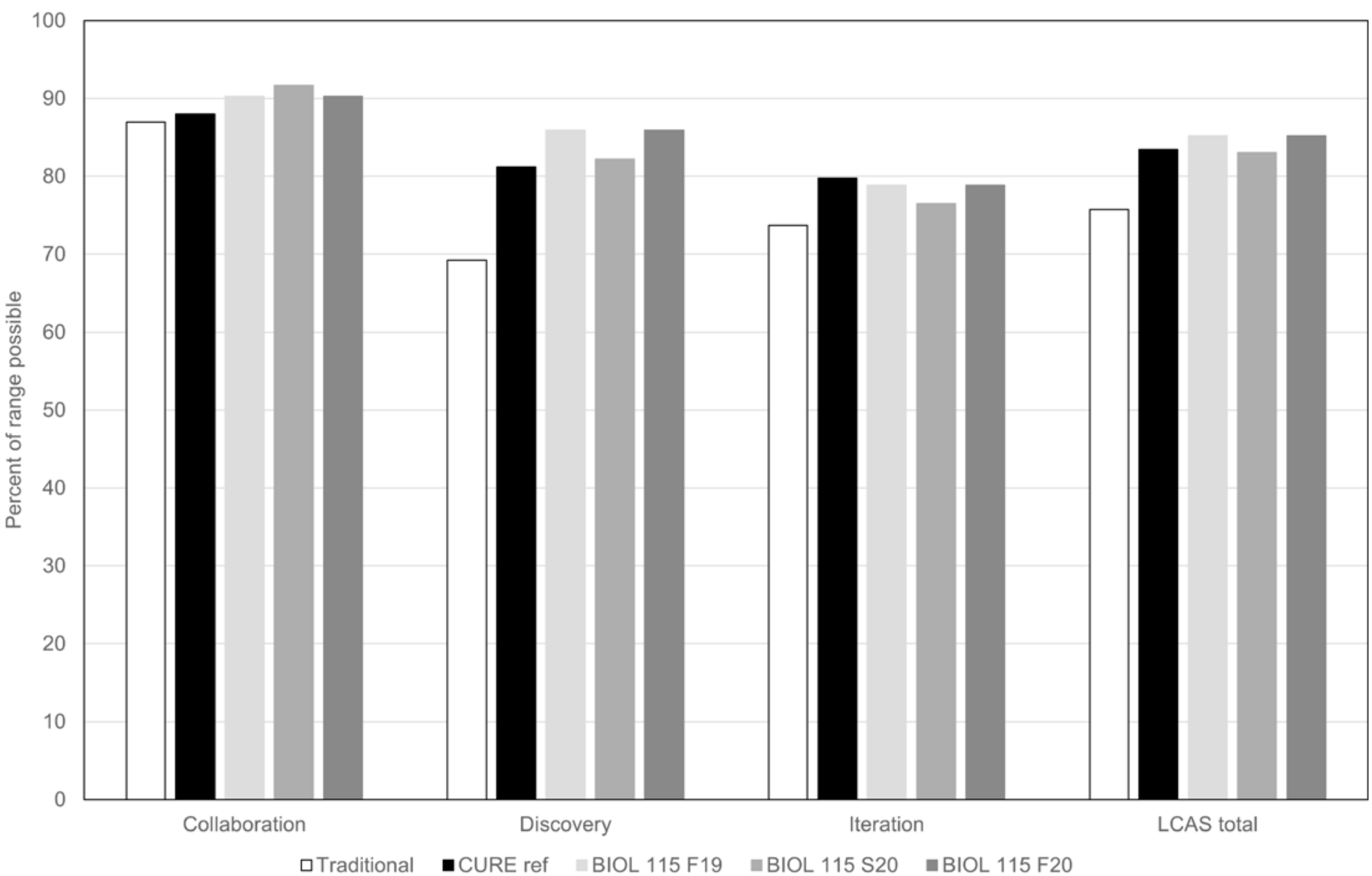


**Figure 2. Results from the Laboratory Course Assessment Survey (LCAS) comparing results from: a published national dataset (Corwin et al., 2015), with traditional lab courses (white) in contrast to CURE courses (black) to the data set for BIOL 115 as CURE across F19, S20, and F20 (gray).**

person/half remote, to a hybrid structure) and notably a complete redesign of the course research project, yet students in remote settings still reported similar levels of learning and skill gains compared to students who took the course under the fully in-person pre-pandemic course structure. To achieve this equivalency, it was necessary to carefully consider student learning outcomes in pre-pandemic semesters and utilize this information to drive the research project and overall course design to achieve key CURE features. Thus, when planning CURE for remote environments, educators should thoughtfully consider how to effectively utilize remote tools, such as collaborative software, to maintain consistency in student experiences with in-person classes.

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**Appendix 1. Supplemental Table 1. Normalized change between mean pre-survey and post-survey scores across the F19, S20, and F20 semesters.** +Indicates questions that do not appear in the original survey, whereas research skill categories in italics were classified by (Reeves et al., 2018).

| | Research Skill Category | F19 Normalized Change Pre/Post | S20 Normalized Change Pre/Post | F20 Normalized Change Pre/Post |
|---|---|---|---|---|
| I feel confident in my ability to construct a testable hypothesis. | *Experimental Design* | 0.44 | 0.47 | 0.57 |
| I could recognize what a testable hypothesis is in an experimental design. | *Experimental Design* | 0.41 | 0.44 | 0.62 |
| I feel confident in my ability to choose appropriate technology (i.e., methods) to answer a research question. | Experimental Design | 0.38 | 0.39 | 0.46 |
| I can recognize what goals are realistic for a research project. | Experimental Design | 0.35 | 0.38 | 0.53 |
| I feel confident in my ability to use scientific articles as a background for a hypothesis. | Literature Skills | 0.43 | 0.44 | 0.60 |
| I feel confident in my ability to assemble a bibliography. | Literature Skills | 0.48 | 0.44 | 0.53 |
| I feel confident communicating the results of a research project to a group of my peers. | *Oral Communication* | 0.43 | 0.39 | 0.57 |
| I feel confident communicating the results of a research project to a group of scientists. | *Oral Communication* | 0.35 | 0.26 | 0.42 |
| I feel confident using technical vocabulary when presenting the results of a research project. | *Oral Communication* | 0.41 | 0.34 | 0.51 |
| I feel confident in my ability to write a paper in scientific format. | *Written Communication* | 0.49 | 0.47 | 0.60 |
| I feel confident in my ability to write a clear and succinct research paper. | *Written Communication* | 0.40 | 0.39 | 0.53 |
| I feel confident in my ability to construct a professional scientific poster. + | Visual Communication | 0.52 | 0.43 | 0.63 |

| | | | | |
|---|---|---|---|---|
| I feel confident in my ability to present a professional scientific poster to my peers.+ | Oral Communication | 0.48 | 0.44 | 0.57 |
| I can recognize when my data have the quality that one expects from published data. | Data Analysis | 0.38 | 0.37 | 0.49 |
| I feel confident in my ability to produce publication-quality results when I perform an experiment. | Data Analysis | 0.31 | 0.29 | 0.44 |
| When working with a group on an experiment, I can effectively divide the tasks between group members. | *Collaboration* | 0.36 | 0.40 | 0.63 |
| I feel confident in my ability to do research with others. | *Collaboration* | 0.45 | 0.45 | 0.64 |
| I find it helpful to work with a team when doing research. | *Collaboration* | 0.47 | 0.45 | 0.60 |
| I feel confident in my ability to work with a team to interpret research data. | *Collaboration* | 0.46 | 0.40 | 0.59 |
| I feel confident in my ability to read and analyze scientific papers. | Literature Skills | 0.39 | 0.35 | 0.56 |
| I feel confident in my ability to understand graphs and tables in scientific papers. | Data Analysis | 0.33 | 0.30 | 0.54 |
| I feel confident in my ability to construct appropriate graphs and tables based on research data.+ | Data Analysis | 0.35 | 0.35 | 0.49 |
| I feel confident in my ability to analyze metagenomic data. **(F19 & S 20).** + | Data Analysis | 0.43 | 0.37 | --- |
| I feel confident in my ability to analyze complex data. **(F20)** + | Data Analysis | --- | --- | 0.30 |