Student Perceptions of Biology laboratory Instruction in Pre, During, and Post-Pandemic: A Comparative Survey Study

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Abstract

In 2020 a global pandemic forced biology teaching laboratories to move to remote instructional environments. In this article, we present data on student perceptions of laboratory instruction modality as experienced pre-, during, and post-pandemic. We designed a survey to evaluate students' perception of key components of scientific critical thinking set as learning outcomes of the laboratories of an introductory biology course. Participants included students who took the course under the same teaching assistant. We surveyed four consecutive semesters, and all populations were evaluated between March 28th and April 10th of 2022, after teaching and learning environments were drastically altered: A) pre-pandemic in-person instruction Fall 2019, B) pandemic emergency-remote instruction Spring 2020, C) pandemic full-semester online instruction Fall 2020, and D) post-pandemic return to in-person instruction Spring 2021. We found differences in the response to four of the nine survey items. First, greater ratings were observed for D relative to C for the following three items: (a) developing research questions and hypotheses, (b) performing experiments and (c) level of engagement. Furthermore, the rating for the Lab quality was greater for D relative to A. There were no differences in students' perception for the following four items: presenting data, performing statistical analysis, discussion of results, and acquiring critical thinking skills. We concluded that students had a better appreciation for in-person laboratories after experiencing remote laboratories. In the future, student perceptions should be considered, along with their academic experiences, whenever laboratories teaching were done remotely.

Keywords: student perceptions, laboratories, instruction modality, pandemic

The outbreak of Covid-19 required a redesign of instruction in higher education. To prevent the spread of the coronavirus-19 (COVID-19), most undergraduate instruction moved to an emergency remote format in March 2020, affecting undergraduate students and educators in natural sciences courses around the United States (Erickson & Wattiaux, 2021). In this work, we defined remote format laboratories as online synchronous instructions, where students and instructors interact in real-time using video conferencing software to resolve problems and work with or without lab simulations. Introductory biology instructors faced numerous challenges in adapting courses during the emergency phase of the pandemic and thereafter. Typically, introductory biology courses are large in enrollment and include a substantial hands-on, and collaborative, laboratory (lab) component (Smith et al., 2005). These courses often include complex learning objectives related to critical thinking and memorization that may be challenging to achieve through remote instruction (Momsen et al., 2010). To cope with emergency remote learning restrictions, biology instructors used creative approaches such as online simulations of cellular and molecular techniques, as well as collaborative data analysis and interpretation in virtual breakout rooms (Delgado et al., 2021; Kearney, 2022). To assist with remote format labs in the microbiology field, Herzog and Mawn (2020) proposed delivering supply kits for students to use at their places of residence (Herzog & Mawn, 2020). Moreover, a study in the animal sciences field showed that students' performance in online and in-person courses was associated with the course modality, the institution, and the number of teaching assistants in the course (Vinyard et al., 2022). Another retrospective study in the physiotherapy field in Italy found improved student performance during emergency remote learning due to the global pandemic versus typical in-person teaching courses (Rossettini et al., 2021). This may be due in part to students having additional time to study during quarantine, without the need to physically travel to classes.

One of the challenges made clear by the emergency remote instruction mandate was the difficulty for students to collect, analyze, and summarize their data as a set of activities meant to achieve key learning objectives of introductory biology courses. In addition, teaching critical thinking and science is challenging itself (Coil et al., 2010). Limited research has documented the impact of emergency remote learning on students' perceptions and experiences in the laboratory. Additionally, few studies have described emergency remote learning alongside in-person and blended instruction. Thus, the work presented here aims to assess how the pandemic impacted students' perception of their critical thinking abilities and the development of their scientific skills in a laboratory course. To consider these issues we surveyed, retrospectively, at the same time frame, students in iterations of a single course section before, during, and after the pandemic in the laboratory component of an introductory biology course (biology 151). The course was offered by the Department of Integrative Biology in a large Land Grant University in the United States. The course was also offered in four consecutive semesters from Fall 2019 to Spring 2021. Because emergency remote instruction at our institution was designed to achieve the same learning outcomes as in-person instruction. We hypothesized that student perceptions of gains in critical thinking and scientific skills would not vary between emergency-remote, in-person, and blended iterations of our introductory biology laboratory course.

Methods

Study Design

Participants included students that previously took the introductory biology laboratory section under the same teaching assistant thus minimizing the "instructor" effect on the results. The Institutional Review Board approved all study procedures (Protocol no. 2022-0187). We designed a survey to evaluate the key components of scientific critical thinking that are learning objectives in the laboratory of Biology 151. We defined critical thinking following the Association of American Colleges & Universities (American Association of Colleges and Universities, n.d.) as "a habit of mind characterized by the comprehensive exploration of issues, ideas, artifacts, and events before accepting or formulating an opinion or conclusion".

After courses were closed and grades published, we sent students an email with an invitation to complete an online survey that was open between March 28th and April 10th of 2022. Using students' self-reported semester of participation, we classified participants based on the modality of instruction and communication software utilized during the corresponding semester. For that reason, this study is retrospective, and the participation was voluntary and anonymous. There were no compensation or credit rewards for participating in this study. We categorized the study responses into four groups, A) pre-pandemic in-person instruction Fall 2019, B) pandemic emergency-remote instruction Spring 2019 using Blackboard Collaborate software, C) pandemic full-semester online instruction Fall 2020 using Zoom software, and D) post-pandemic in-person instruction Spring 2021 (see Table 1). To quantify the students' learning perception, we designed a nine-question item survey (see Table 2).

Course Description

At our institution, Introductory Biology is offered as a series of two courses through both the College of Letters and Sciences and the College of Agricultural and Life Sciences. Introductory Bio 151 is a 5-credit full-semester course that continues with Bio 152 in the second semester. These courses are required for undergraduates in majors such as the biological sciences, molecular biology, neurobiology, and zoology. Typically, students who enroll in these courses are interested in perusing further study in graduate or professional school. For instance, many past students have pursued advanced degrees in medicine, veterinary, dentistry, and psychology.

Our study focused on the laboratory component of Bio 151, which includes lectures and discussion sections. The laboratory learning objectives are divided into two

Table 1.

Modality of instruction in the introductory biology labs.

Abbreviation	Semester	Description
A	Fall 2019	Pre-pandemic instruction. In-person before the pandemic, hands-on teaching laboratories.
B	Spring 2020	Pandemic transition to emergency-remote instruction. In-person instruction for the first 8 wk., emergency remote instruction for the final 7 wk. of instruction using Blackboard Collaborate (BBCollaborate) video-conferencing software.
C	Fall 2020	Pandemic full-semester remote instruction using Zoom video-conferencing software.
D	Spring 2021	Post-pandemic return to in-person instruction. In-person instruction was like pre-pandemic.

Table 2.

Survey items and general category questions; the 9 items were to assess students' perception of their critical thinking acquisition and development of scientific skills. Respondents reported their perceived gains using an anchored scale from 1 (None) to 10 (Significant)[1].

Category	Item	Short Description	Long Description (Actual item)
Learning scientific skills	1	Formulate questions and hypotheses	This laboratory allows you as a student to perform a variety of tasks, make a research question and develop hypotheses. How much do you think you learned from these skills in the laboratory?
Learning scientific skills	2	Perform experiments	How much do you think you learned to make observations, design, and perform experiments to test the hypotheses?
Learning scientific skills	3	Present data	This laboratory allows you as a student to perform a variety of tasks, including presenting data. How much do you think you learned of these skills in the laboratory?
Learning scientific skills	4	Perform statistics	This laboratory allows you as a student to perform a variety of tasks, including statistical analysis. How much do you think you learned of these skills in the laboratory?
Learning scientific skills	5	Discuss results	The laboratory allows you as a student to perform a variety of tasks, including a discussion of your results. How much do you think you learned of these skills in the laboratory?
Gain in self-efficacy for learning critical thinking	6	Confidence in critical thinking	Please indicate your confidence in your ability to do the following from "not confident" to "confident" BEFORE the course and NOW acquiring critical thinking.
Quality of instruction	7	Lab quality	How would you rate the overall quality of the laboratory?
Engagement	8	Engagement	How would you rate your level of engagement in the course?
Learning critical thinking	9	Gain in critical thinking	How much do you think the content of the course improves your critical thinking?

Note. [1]No further instructions were provided; Interpretation of the scale was made individually.

parts. First, students work to understand the structures and functions of basic components of prokaryotic and eukaryotic cells, how these organelles are important to utilize energy to maintain cellular homeostasis, and the cellular components underlying mitotic cell division. Second, students apply their knowledge of cell biology in particular examples by using basic cell biology techniques. For instance, using techniques such as light microscopy or polymerase chain reaction (PCR). To develop the ability to think, collect and analyze data, and then present their findings scientifically, students work in small laboratory groups with their open research questions to investigate. For each unit, students set up experiments to collect and analyze data before writing a brief research paper or lab report (Philosophy of Introductory Biology 151-152 Laboratory, n.d.). The laboratory component of the course comprises 30% of the total grade. The laboratory takes place once a week for three hours during which students work in teams.

Statistical Analysis

First, for each item, we used a one-way ANOVA to test the null hypothesis that the means of A, B, C, and D populations were all equal. Second, for items where the

F-test indicated differences (P<0.05), we tested all possible pairwise differences with two-sample T-tests (Meier, 2006). Pairwise tests were evaluated using a Bonferroni correction for multiple comparisons to minimize false positives (Haynes, 2013). Data were analyzed with the Analysis ToolPak add-in package of Microsoft Excel spreadsheet (Microsoft Excel 2018, 2018).

Results

For each learning modality, a similar number of students were enrolled in the course: A = 68, B = 63, C = 65, and D = 65 students. In all these courses, the survey response rates were moderate. Total responses were A = 17 (25%); B = 10 (16%) C =16 (25%) and D =22 (34 %). We assumed that selection biases were homogenous across learning modalities to allow for comparison.

The ANOVA indicated no overall differences for five items: presenting data, conducting statistical analysis, discussing results, confidence in critical thinking, and gaining in critical thinking due to learning modality ($p \geq 0.05$). We observed significant differences in four items: Formulate research questions and hypotheses, performing experiments, lab quality, and engagement based on the learning modality (Table 3). We observed significant differences in C and D, where D reported greater scores, $p<0.05$ (Figure 1). Students who took the course in person (A pre-pandemic and D post-pandemic) reported greater engagement compared to those who took the course remotely during the pandemic (B and C), $p<0.05$ (Figure 1). Thus, returning to the in-person modality after remote instruction may have led students to enact and/or perceive greater engagement in the in-person laboratory.

Discussion

These results display that students' perceptions of learning gains varied between remote learning and in-person. First, students appreciated creating research questions and developing hypotheses. Second, students showed that they learned more by making observations, designing, and performing experiments to test a hypothesis. Third, students exhibited a greater appreciation for in-person lab engagement after experiencing online laboratory experiences. Finally, the data shows that students rated the quality of laboratories higher after the pandemic as compared to before online semesters.

At our institution, the introductory biology laboratories are designed such that students typically use scientific methods to investigate realistic, open-ended problems to discover biological concepts that supplement learning in lectures. Our laboratories emphasize the development of written and oral skills through formal presentations given after students carry out their experiments. The current research provides data for deepening our understanding of how to help students engage in learning biology through various learning modalities and under emergency conditions.

Learning scientific skills in labs involves collecting, analyzing, and presenting data to respond to a scientific question. Recent reports show some aspects of biology teaching where online learning may have advantages over in-person instruction. For example, collaborative document-sharing platforms can make it easier to collect, graph, analyze, and present data virtually than in-person (Lichti et al., 2021). Recent investigations have demonstrated that the transition to online pedagogy during the COVID-19 pandemic did not detrimentally affect students' academic performance in undergraduate animal genetics and animal physiology courses. However, it did result in a reduction of student contentment with the remote learning experience

Table 3.

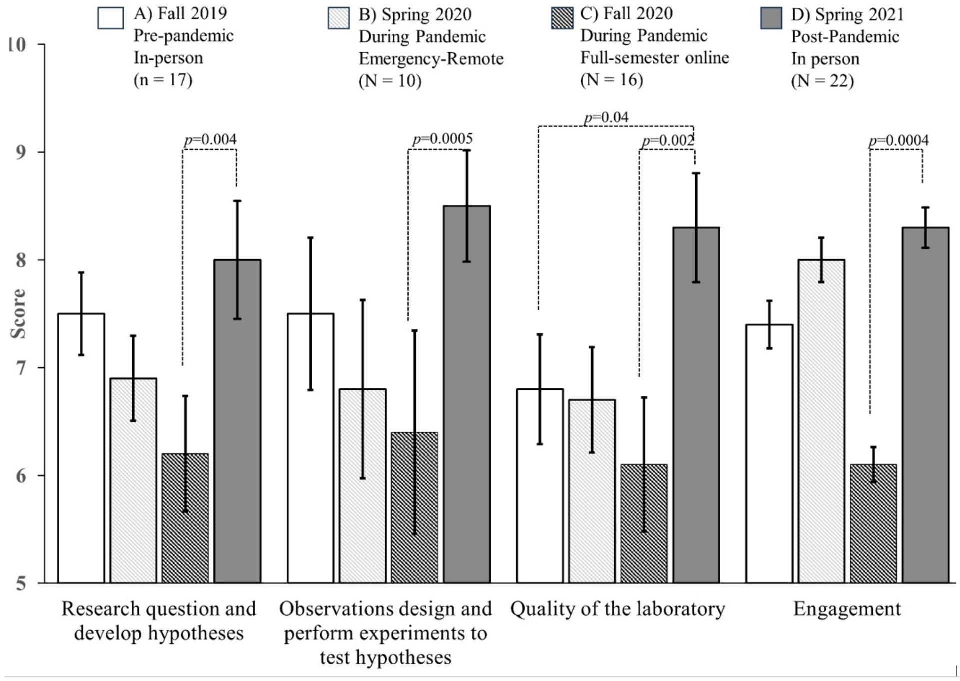
Impact of 4 modalities of teaching and learning biology laboratory on students' perception of learning gains[1].

Item[1]	A[2]	B[2]	C[2]	D[2]	SEM	P value
Formulate questions and hypotheses	7.4	6.9	6.1	8.0	1.67	0.01
Perform experiment	7.4	6.8	6.3	8.5	1.72	<0.01
Present data	6.6	6.7	6.8	7.8	1.81	0.13
Perform statistics	6.5	6.1	6.8	7.0	2.27	0.73
Discuss results	7.5	7.0	6.6	8.0	1.85	0.14
Confidence in critical thinking	7.2	6.5	6.7	7.4	1.86	0.26
Lab quality	6.8	6.7	6.0	8.2	2.07	0.01
Level of Engagement	7.3	8.0	6.1	8.2	4.49	<0.01
Gain in critical thinking	6.4	6.1	5.7	7.0	1.96	0.26

Note. [1]scores are the mean ratings of survey items on a scale of 1 (None) to 10 (Significant).
[2]A = Fall 2019, Pre-pandemic in-person, n = 17; B = Spring 2020, during the pandemic, Emergency remote, n = 10; C = Fall 2020 during the pandemic, online, n = 16, D = Spring 2021, post-pandemic, in person, n = 22.

Figure 1.

Bar chart showing average score on a scale of 0 (none) to 10 (significant) for the selected survey items for which significance ($p < 0.05$) was declared among learning modalities: A) pre-pandemic in-person instruction Fall 2019, N = 17; B) pandemic emergency-remote instruction Spring 2020, N = 10; C) pandemic full-semester online instruction Fall 2020, N = 16, and D) post-pandemic return to in-person instruction Spring 2021, N = 22. Dashed connecting lines indicate statistical differences with the corresponding P values (p) after Bonferroni correction.



(Vautier et al., 2023). Our results showed that students felt online lab experiences taught them how to formulate research questions, develop hypotheses as well as design and perform experiments to test hypotheses. This may have contributed to their appreciation for the overall quality of the laboratory and how they rated the level of engagement in the course.

Our data showed that overall students valued the lab environment in D (On-line), especially in comparison to C (in person). Perception of critical thinking acquisition appeared less affected by the online learning modality, compared with learning of laboratory skills. Previous research showed that students and instructors were able to collect data and collaborate online. For example, Paradise & Bartkovich (2021) and Richer (2021) indicated that students could successfully identify insect species whether the labs were in-person or offered remotely. Furthermore, these authors reported that students showed high rates of collaboration in learning biology online (Paradise & Bartkovich, 2021; Richter et al., 2021). Complementary to this, our data suggest that online experiences increased student perception of learning scientific skills, including developing research questions and hypotheses and performing experiments, but did not impact grades (data not shown). As our data were longitudinal, students were further along in their academic experience in the Spring of 2021 and thus might have gained an appreciation for in-person learning opportunities after experiencing all their courses online in the Fall of 2021.

We identified four interrelated limitations of the present work. First, intrinsic to the experimental design, the study focused on students' self-reported perception of learning and engagement. These self-reported measures imply subjectivity, which may depend on emotional state, recollection, and other factors influencing the state of mind of the participants at the time of survey completion. Second, the retrospective nature of our study created limitations in students' views could have shifted over time. However, this retrospective approach ensured that all students had been subjected to the same major shifts in instructional modalities before, during, and after the pandemic. The third limitation of this study is that the response rates for the survey-based evaluation were relatively low. This may indicate a potential bias in the interpretation of the results. Finally, it is unclear from the reporting whether the sample is demographically representative, which may limit the generalizability of the findings to the broader population of undergraduate students.

Students have reported positive opinions of online teaching, particularly online communication with instructors in introductory biology courses (Gibson & Shelton, 2021). Overall, our data showed minimal differences in the self-reported experience of students taking the labs online, in-person, or in a blended modality, particularly for their perceptions of the course's effect on their learning of critical thinking. Interestingly, the authors reported also that students who chose to take the course online performed better than those who took the course in person as evidenced by their grades.

Conclusion

Teaching and learning have been transformed dramatically due to the global pandemic. Our current research is relevant to preparing for future scenarios in two ways. First, as more post-pandemic science courses include online components, instructors can better understand student learning in online labs. Such online instruction might help prepare students for a new and emerging remote work environment that may become more prevalent in the mid-21st century. Second, administrators in institutions of higher education can better understand some factors that affect learning content and acquisition of professional skills based on the modality of instruction. Thus, future research should address further some of the findings of this study. For example, how is in-person post-pandemic instruction different from in-person pre-pandemic instruction? How do student expectations shape their perceptions of post-pandemic instruction? How to design and implement laboratories to achieve positive learning outcomes remains an exciting challenge for instructors and teaching assistants around the world. Research in this area, however, would prove invaluable as online teaching is emerging as part of a new post-pandemic paradigm in higher education, or when the next emergency remote instruction mandate comes into effect because of a future pandemic.

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