An Online Introductory Biology Laboratory Utilizing Inquiry-Based Methods Leads to High Student Satisfaction

By Colin Harrison, Clarke Britton, Hannah Shin, and Yassin Watson

Online laboratories can be an effective way to introduce students to lab concepts while providing flexibility, increased access, and reduced costs. However, online labs might lack the authentic research experience that can be gained by doing hands-on lab work. This study explores student perceptions of an online, inquiry-based introductory biology lab. Students participated in a semester-long curriculum during summer 2020. Upon completion of the course, students responded to a survey about their thoughts and attitudes toward the material and mode of delivery. Overall, students perceived the course favorably, with more than 90% of students indicating that they were satisfied with the course. Students had strong positive impressions of the writing-intensive sections of the course, which included a research proposal and a lab report. They also recognized that these components helped contribute to their own learning. This positive influence on student perceptions indicates that an online inquiry-based lab can be an effective means for student participation in biology labs when in-person lab options are not available.

A s online education opportunities have expanded, educators have needed to quickly adapt peer-reviewed methods and techniques to an online format. This shift of college-level education to the use of online platforms in addition to face-to-face instruction has allowed for greater access to these educational opportunities for many people (Faulconer & Gruss, 2018; Perera et al., 2017). In addition to an already growing trend toward providing online options, the COVID-19 pandemic forced a large shift from in-person to online education as colleges adapted to the reality of conducting classes during a pandemic. As educators grappled with the new normal of teaching in an online world, it is important to focus on incorporating innovative pedagogical strategies to maintain the quality of education in online learning environments.

Although online modes of content delivery can be effective for teaching and learning, converting laboratory courses to an online format has proved challenging (Reese, 2013; Scheckler, 2003; Son et al., 2016; Stuckey-Mickell & Stuckey-Danner, 2007). Completing hands-on biology labs at home can be difficult due to the specialized materials and safety procedures needed for many biology labs. Many of the online biology lab courses that currently exist utilize simulations to provide a lab experience for their students (Dikke et al., 2014; Hossain et al., 2017; Munn et al., 2017; Whitworth et al., 2018). Although simulations can be an important tool for online learning, they lack several important features that make laboratories beneficial for student learning (Reese, 2013; Scheckler, 2003; Son et al., 2016). In simulated environments where students are given computer-generated sets of data, they miss the opportunity to make mistakes with experimental design and navigate the inherent messiness of real-world data (Schultheis & Kjelvik, 2020).

This absence of real-world variation may cause students to feel like they are not doing a worthwhile and novel experiment, potentially further lowering their engagement levels (Brockman et al., 2020; Pyatt & Sims, 2011). Additionally, the omission of real hands-on time with equipment and experimental setups can be detrimental to the potential for students to cultivate a sense of ownership over their projects (Brockman et al., 2020; Pyatt & Sims, 2011). There have been some positive examples of students being able to manipulate actual experimental conditions with an online platform, but these situations typically require specialized tools that may...
inhibit widespread adoption (Corter et al., 2011; Hossain et al., 2017; Kennepohl et al., 2004).

One important aspect in which online lab education could improve is through the use of inquiry-based laboratories and coursework that use real data. Inquiry-based laboratory education has been shown to increase engagement and provide more learning gains than more traditionally oriented laboratory structures (Deters, 2005; Hermansyah et al., 2019; Ketpichainarong et al., 2010; Pyatt & Sims, 2011; Russell & Weaver, 2011; Spiro & Knisely, 2008). Students who participate in inquiry-based labs demonstrate greater ownership over their projects, as they are responsible for guiding the individual aspects of their own research (Gormally et al., 2009; Hanauer & Dolan, 2014). Although inquiry-based labs provide a great opportunity for students in a face-to-face environment, there is little research on the way in which inquiry-based labs that use real data can be incorporated and adapted into an online environment.

Online labs have their downsides and challenges, but there are several positive aspects that can provide an effective learning environment for students while increasing access to these learning opportunities. Students in online labs show a similar level of performance on assessments to students participating in face-to-face labs under certain conditions (Estriegana et al., 2019; Faulconer & Gruss, 2018; Pyatt & Sims, 2011). Depending on the setup of the online labs, students can work on lab assignments on their own schedules, providing added flexibility for students’ learning (Brockman et al., 2020). Students also have less apprehension about making errors in the experimental setup, which would lead to failed experiments (Jones, 2018; Wiesner & Lan, 2004). Online labs can also lead to reduced costs, allowing for increased accessibility for a larger audience (Brockman et al., 2020; Dikke et al., 2014; Perera et al., 2017).

Given the lack of studies on inquiry-based online labs and the potential benefits, it is important to model and study new ways in which educators can incorporate inquiry and real research data into the online learning environment. By better understanding student experiences in these settings, we can set our students up for success and improve learning outcomes. These survey data enable us to explore (i) students’ perceptions of an online inquiry-based course with real data, (ii) students’ engagement with the online materials, (iii) students’ perceptions of online materials’ usefulness, (iv) students’ engagement with ownership over their experiments, and (v) ways in which this laboratory could be improved in the future.

**Class structure and student survey participation**

This study was done in summer 2020 as classes were forced to shift online due to the COVID-19 pandemic (Institutional Review Board Protocol H20320). The course in the study is the first semester of nonmajors introductory biology at a midsize R1 university in the southeastern United States. Students in the course ranged from having just completed their first year of college to being in their final semester before graduation. The course was co-taught in three sections, each of which was led by two graduate student teaching assistants. Enrollment in the three sections was 10, 18, and 19 students, respectively. Lab sections met once per week for 9 weeks both synchronously and asynchronously. Teaching assistants were responsible for online course administration and grading, spending an average of 10 to 15 hours per week, depending on grading responsibilities. During the semester, students completed three different experiments, each lasting 3 weeks and all of which used the same general structure.

During the first week, students completed a prelab assignment in which they had to propose their own individual experiment based on data and procedures provided in their lab manuals. They then attended a synchronous online session in which teaching assistants presented a short, active-learning-focused presentation about the background of the experiment in question. Students then worked in breakout groups (average of three students per group) to generate a research proposal for their experiment. Once the students submitted their proposals, the biology lab coordinator set up and collected data as outlined in the students’ research proposals. This collected data took the form of images, movies, and raw data tables, depending on the experiment in question. In the second week, students received these data for analysis. Students were encouraged to run the analysis solo before meeting with their lab group members for further data discussions. The second week of the course happened mostly asynchronously, with students required to attend short 10- to 15-minute individual meetings with their teaching assistants, who would check on the students’ progress and answer any lingering questions. Students were also tasked with writing individual lab report drafts for submission.

During the final week, students presented their research findings synchronously via online presentations. Although students could work on their presentations in tandem with their groups, one individual
from each group was responsible for the presentation. Students then provided feedback on their peers’ lab report drafts. Students also met in small breakout sessions to discuss their feedback. (For a lab structure example, see Figure 1 or access full lab materials at https://drive.google.com/drive/folders/16XMzkXy4BqL09D2gWCxm2rdyXw9gedJY?usp=sharing.) At the conclusion of the course, students had the opportunity to complete a survey about their experiences with the course. The survey was administered anonymously, and all students received extra credit, regardless of survey completion. Of the 47 individuals who were enrolled, 36 completed the entire survey and one completed part of the survey.

**Survey results**

Of the 36 individuals who completed the survey, 31 had previously taken an in-person lab course at the university. Of those individuals, 14 thought the online course was better than their other experiences with labs, with four rating the lab as much better, four as moderately better, and six as slightly better (45.2% overall). Ten individuals thought this course was about the same as their previous lab experiences (32.3% overall). Seven individuals rated the online intro bio lab as worse, with six selecting slightly worse, one moderately worse, and none selecting much worse (22.6%). The mean value of the data was 3.25 (SD ± 1.36), corresponding to slightly better, while the median was 4, corresponding to about the same (Figure 2). Representative quotes from each category

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**FIGURE 1**

Example lab structure for genetics module.

The overall goal of this lab is to study how disrupting the gene expression of muscle genes using RNAi can affect *C. elegans*, development, and movement. Students are tasked with doing background research for their chosen gene of interest (act-3, deb-1, lev-11, unc-60, unc-78) and how it relates to human disease pathology. In this scenario, they are developing *C. elegans* models to test drug development for treating muscle disorders.

<table>
<thead>
<tr>
<th>Lab week</th>
<th>Lab activity</th>
<th>Assignments due</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>• Background lab presentation by TAs on <em>C. elegans</em> biology and RNAi • Student lab groups work in breakout sessions, doing background research and preparing their research proposals.</td>
<td>• Prelab (before class)</td>
</tr>
<tr>
<td>2</td>
<td>• Students are given videos of <em>C. elegans</em> movement assays and tasked with calculating the number of thrashes in worms affected by RNAi. • Students provide a data file at the end of their lab day with their calculations and any stats work.</td>
<td>• Research Proposal</td>
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<tr>
<td>3</td>
<td>• Students present their work in short 8- to 10-minute presentations. • Students review three of their peers’ drafts and then meet to discuss in breakout sessions.</td>
<td>• Lab Report 1 Draft • Presentation • Final Lab Report due the following week</td>
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**FIGURE 2**

Likert plot comparison of student perceptions of in-person and online laboratory.

![Likert plot comparison](https://drive.google.com/file/d/16XMzkXy4BqL09D2gWCxm2rdyXw9gedJY/view?usp=sharing)
When asked about their overall satisfaction with the course, students were overwhelmingly positive. Thirty-three individuals had a positive experience in the lab, with 16 individuals extremely satisfied with their experience, 11 individuals moderately satisfied, and six individuals slightly satisfied (91.7% overall). Only one individual was neutral on the question (2.8% overall). Two individuals were unsatisfied with their experience, with one slightly dissatisfied and one moderately dissatisfied (5.6% overall). No students selected extremely dissatisfied. The mean value of the data was 1.92 (SD ± 1.19), corresponding to moderately satisfied, while the median was 2, also corresponding to moderately satisfied (Figure 4).

To gain a better understanding of how the individual components of the lab influenced student perceptions, we measured students’ experiences and perceived learning with these activities (Likert scale of 1 to 7, 1 = extremely positive, 7 = extremely negative). The majority of students had a positive experience with almost every activity other than the peer review breakout sessions, which were rated as neutral overall (mean = 3.42 ± 1.61, median = 4). None of the components had an overall negative rating. Lab Report Drafts (mean = 1.63 ± 0.99, median = 1) and Data Analysis File (mean = 1.78 ± 0.92, median = 1.5) were the top-rated components. All other components had a median score of 2, corresponding to a moderately positive experience. No students selected extremely negative for any of the components (Figure 5).

In addition to the positive experience, the majority of students felt the class activities contributed to their learning to some degree (Likert scale of 1 to 4, 1 = contributed a lot, 4 = did not contribute). The writing-intensive components Research Proposal (mean = 1.53 ± 0.73), Lab Report Drafts (mean = 1.58 ± 0.68), and Final Lab Report (mean = 1.54 ± 0.73) all had median scores of 1, corresponding to the response that they contributed a lot to students’ learning. The Provided Data component also had a median of 1 (mean = 1.58 ± 0.68). Group Breakout Sessions for Draft Feedback was the only component with a median score of 3, which corresponded to students’ feelings that this component slightly contributed to their learning (mean = 2.86 ± 1.00). All other com-

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**FIGURE 3**

Sample quotes about student perceptions of in-person vs. online laboratory.

### Positive

- Having to go through the whole process of building up a hypothesis and an experiment helped me understand the concepts of the lab much better. In previous lab classes, we didn't spend a lot of time in the preparation and the reasoning behind the experiments and just dived right into the lab work. This felt a lot more thorough, even though we couldn't do the experiments ourselves.
- Having the experiments carried out for us but none of the data calculated helped me understand why certain parts of the experiment were done without having to worry about the risk of sabotaging my own experimental design if I were to carry out the experiment on my own.
- Online labs seemed to be very heavy on data analysis and presenting ideas, which in my eyes seems to be a lot more representative of actual research and what it requires.

### Neutral

- The coursework and way in which it was present was very similar to that of an in-person course; the only thing that seemed to differ was the presentation aspect and the lack of physically being in lab.
- I felt that the online science lab and my in-person science lab compared the same. I was still able to gain a good understanding of the experiments and their purpose without having to be in person to do so. If anything, I felt the instructions for the online labs were more clear compared to my in-person labs.

### Negative

- Because we aren't getting hands-on experience, explaining the methods in lab reports and understanding that lab took a little while longer. We were also doing just as much work as normal without the hands-on portion of the lab or actually being able to work in groups.
- It’s harder to be engaged when you’re not conducting the experiment yourself.
FIGURE 4
Likert plot of overall student satisfaction with online laboratory.

FIGURE 5
Multiple Likert plot comparison of students’ experience with components of online laboratory.
FIGURE 6

Multiple Likert plot comparison of student-perceived contributions to learning through components of online laboratory.

FIGURE 7

Likert plot of student-perceived sense of ownership over research projects.
ponents had a median rating of 2, corresponding to moderately contributed (Figure 6).

Students were asked whether they had perceived ownership over their projects. Overwhelmingly, students felt they had ownership over their projects, with no students selecting that they felt no ownership over their projects. Students perceived a little (16.7%), a moderate amount (50.0%), and a lot (33.3%) of ownership over their research projects, with an overall mean of 1.83 ± 0.69 and median of 2, corresponding to a moderate amount of ownership (Figure 7).

Finally, students were asked what positive experiences they took from the lab and what changes they would suggest for the lab in the future. Sample quotes from these two questions are displayed in Figure 8. Overall, students enjoyed the structure of the course and the ability to move from an initial hypothesis to testing through self-designed experiments. Students also appreciated the ability to collaborate with one another and the instructional team. Although individual students had different suggestions, one common theme for improvement was that students should get more background information prior to experimental design in the prelab assignments.

**Discussion**

Online education continues to grow in importance for how students interact with their course content. As educators, we must continue to innovate in the ways in which we deliver online content. This is especially true for laboratory courses in which hands-on learning is a vital part of the education process. We have demonstrated that you can achieve high levels of student satisfaction while maintaining an inquiry-based lab that uses real data in an online introductory biology course.

**Students’ experience compared with in-person labs**

The majority of students (77%) with prior lab experience rated this lab as better or the same as their previous lab experiences. This could be the function of biology lab courses providing a more satisfying experience than other lab courses at the university, but student quotes seem to indicate that they recognize the value of the online session. To illustrate this point, one student stated:

> Having to go through the whole process of building up a hypothesis and an experiment helped me understand the concepts of the lab much better. In previous lab classes we didn’t spend a lot of time in the preparation and the reasoning behind the experiments and just dived right into the lab work. This felt a lot more thorough, even though we couldn’t do the experiments ourselves.

Another student added that the online lab “seemed to be very heavy on data analysis and presenting ideas, which in my eyes seems to be a lot more representative of actual research and what it requires.” These themes were echoed by several students in the survey. Although the majority of responses were positive, the negative respondents made up a notable portion of the feedback. Most of the negative comments from students revolved around the lack of getting hands-on time with the experiments and how this negatively affected their connection with and understanding of the project. This indicates that even

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**FIGURE 8**

Sample student responses to two survey questions.

<table>
<thead>
<tr>
<th>What are your positive takeaways from lab this summer?</th>
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<tbody>
<tr>
<td>• I really enjoyed the ability to still understand and feel as if I had done the lab in person even if I did not. The prelabs provided adequate information so that I could feel prepared and better understand what was expected of me for each lab.</td>
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<tr>
<td>• I learned the material—that’s always good. In all seriousness, though, good work to all the instructors and TAs, who likely spent countless hours retrofitting a physical lab to an online format. It’s clear that you all wanted this to work as smoothly as possible, and I hope that post-COVID, Bio continues to offer an online format for introductory labs, even if only one section.</td>
</tr>
<tr>
<td>• I had a really good lab group with two awesome students who I was able to discuss problems and ideas with often. Additionally, the TAs were very supportive and thorough when giving advice after our presentations.</td>
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</table>

<table>
<thead>
<tr>
<th>What things would you change in a potential future online lab?</th>
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</thead>
<tbody>
<tr>
<td>• I would suggest to make the initial presentations a little clearer because sometimes prelabs were difficult when it was a new topic we hadn’t learned in class yet.</td>
</tr>
<tr>
<td>• For future online lab, I would maybe include more initial explanation of the lab when we start a new unit because it was confusing at first to try an devise an experiment in the prelab when there was no prior explanation of what we were being asked to do.</td>
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</table>
though online classes can be a positive experience for students, they are not a complete substitute for getting hands on with the material. Given this information, it may benefit students to conduct at least one experiment in which they collect data from their own environment. An experiment in which they collect measurement data over the course of the semester (e.g., ecological monitoring) could be a valuable way for students to gain hands-on experience in addition to the online lab opportunities. One student suggestion from the survey was to have videos of the instructional team carrying out the experiments to help students understand the experimental procedure.

**High student satisfaction**

Overall, students were satisfied with their experience in the online setting (91%). They appreciated the structure of the course, with several students stating that they liked being given the time to explore each laboratory activity, which helped them achieve a better level of understanding of the lab and the subject matter. To illustrate this point, one student said, “Having multiple weeks to discuss each lab to ensure our full understanding of its main concept, as well as scheduled meetings with the TAs to ask questions, is fantastic.” This feedback indicates that giving students sufficient time in each laboratory activity is vital to their experience in online labs. It may be that a “less is more” approach to the number of labs and amount of content is the most beneficial approach to the student learning experience.

**Satisfaction with most course activities and the way they contributed to learning**

Students were satisfied with the activities in the course and felt that they contributed to their learning. In particular, the writing- and research-intensive Research Proposal and Lab Report Drafts components were rated highly by the students. Allowing students room to explore their ideas related to the subject is extremely beneficial to their learning process and can help them connect with the material (Son et al., 2016). One potential reason that these assignments were so effective is that they deliberately connected the lab science to real-world issues. Within the Research Proposal component, students were given a real-world scenario in which they were scientists working on an issue related to that particular experiment. They were tasked with thinking like a scientist in this role and relating their background research and findings to these specific real-world solutions. Connecting laboratory activities to real-world solutions can lead to greater student engagement (Hanauer et al., 2018; Rodenbusch et al., 2016).

Conversely, there were a couple activities that students perceived as less effective and were brought up in the comments regarding course improvements. Many felt that there was nothing to talk about in the breakout sessions discussing peer feedback, as they had already provided their written feedback. One student said:

> The TA meetings weren’t terribly helpful for me, and neither were the peer-editing breakout sessions. By the second peer-editing session, nobody was really talking to each other, and I can’t really blame them; it makes more sense to type out your edits and submit them anyway.

Although explaining feedback can be a valuable process, this type of activity may need a little more scaffolding on the instructional side for it to be effective.

Another aspect that came up several times in the students’ discussions were the prelabs. The students recognized the value in the assignment, but many stated that they did not feel prepared to proceed with the assignment without further context. One student said:

> For future online labs, I would maybe include more initial explanation of the lab when we start a new unit because it was confusing at first to try and devise an experiment in the prelab when there was no prior explanation of what we were being asked to do.

The goal of these prelabs was to get students thinking about the topic at hand, but it may have been better to explore what students knew instead of having them design an experiment before they have explored the topic.

**Ownership felt over students’ projects**

Every student felt a sense of ownership over their projects, with most feeling like they had at least moderate ownership. The structure of the lab and assignments may have benefited students’ feelings of connection with the experiments. In addition, this is an area where the inquiry nature of the labs may be extremely important, as studies have shown how much more effective inquiry labs are for student ownership (Brockman et al., 2020; Pyatt & Sims, 2011). Using real data, which meant the stu-
students had to struggle with imperfect answers, might have also increased this sense of ownership because they felt responsible for their data (Gormally et al., 2009; Schultheis & Kjelvik, 2020). Anecdotally, students were invested in the struggle to make sense of inconsistent data or to explain data that did not fit their original hypothesis. Connecting these data back to the big-picture subject matter really helped students understand how science works.

**Limitations**

Although this study did show high overall levels of student satisfaction, there are some limits to the larger takeaways and reproducibility of the learning environment. Because this was a summer course, almost all the students had already had prior experience in the college setting; additionally, because students are not required to take courses during the summer, there may have been some self-selection effect for students who were highly motivated. In addition, this study was done with a relatively small sample size and may not capture all the viewpoints of potential students. This course uses real data set up by the instructional team, so it does require significant time and effort for the setup and collection of data for students’ experiments. In environments where fewer resources are available, further limiting student choice might make the workflow more feasible, with the downside of less student agency within the experiment.

**Conclusion**

There are some minor changes that could be made to this lab structure to improve the experience for the students, but the lab was extremely successful overall in engaging students in the process of doing science. By focusing on inquiry labs with real data, students could approximate the experience of in-person labs in an online setting. The structure of the course allowed students to successfully connect with the material and the scientific process. The success of this course shows that inquiry-based labs are doable in an online setting and can serve as a potential model for moving other biology laboratory courses online.

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**References**


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