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Student Perceptions of an Inquiry-Based Molecular Biology Lecture and Lab Following a Mid-Semester Transition to Online Teaching

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Student perceptions of an inquiry-based molecular biology lecture and lab following a mid-semester transition to online teaching

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Abstract

The transition to online learning in spring 2020 was abrupt for both students and instructors. While many instructors moved to asynchronous classes, some institutions relied more heavily on synchronous online courses. Here, we evaluate student perceptions of an inquiry-based molecular biology lecture and lab course following this transition by comparing student survey responses from spring 2019, when the lecture and lab were fully in person, to spring 2020, when the lecture and lab started in person before transitioning to a synchronous online format. Students were asked to identify the main factors that supported their learning in lecture and lab, characterize the main barriers to learning in those courses, and discuss their preference of having an inquiry-based lab or a traditional "cookbook" lab with pre-determined answers. We coded these responses and provide one of the first studies to examine the impact of this online transition on student perceptions of learning in an inquiry-based molecular biology lecture and lab course.

Keywords: active learning, online learning, inquiry-based labs

Introduction

Many institutions of higher learning transitioned to online learning in spring 2020 due to the COVID-19 pandemic [1]. This abrupt transition posed many challenges for students, who faced increased stress and anxiety as well as potential increases in social isolation [2-3]. Instructors, similarly, were tasked with moving classes to remote instruction with often very little notice and training, an especially acute challenge for those courses in spring that were already underway and had been designed for in-person instruction. While some instructors shifted to asynchronous learning, others attempted to translate the in-person course experience to synchronous online classes. However, while past work has investigated student perceptions of online learning [e.g. 4-7], few studies have explored the impacts of a sudden mid-semester transition to online learning on student perceptions of learning, particularly in the context of the COVID-19 pandemic.

Here, we focus specifically on student perceptions of supports and barriers in an inquiry-based molecular biology lecture and lab course that transitioned to synchronous online learning in spring 2020. We compare student survey responses in spring 2019 (when the lecture and lab were conducted fully in-person) to those in spring 2020 (when the lecture and lab started in person but shifted online) to answer the following three questions:

1) What did students identify as the main factors that supported their learning in this class, and how did these factors change between the fully in-person iteration of the course in spring 2019 and the spring 2020 iteration of the course that began in-person but transitioned to online learning?
2) What did students identify as the main barriers to their learning in this class, and how did these factors change between spring 2019 and spring 2020?

3) How do students perceive this exploratory lab, and what impact, if any, did the transition to remote learning and the inability to finish the lab project impact student perceptions?

These questions are particularly relevant given that the molecular biology courses studied here relied heavily on active learning, which has been identified as one of the four main factors (along with student-faculty interaction, time on task, and cooperation among students) that promote effective online teaching [8-9]. Active learning is a broad approach that encompasses many different pedagogical techniques, ranging from problem solving to think-pair-shares to discussions [10-11], and can promote student engagement in online courses [12-15]. Despite this, few studies have specifically examined student perceptions of active learning following a mid-semester transition to online learning. As such, we were interested in determining if there was a change in how students perceived the frequent inquiry-based small-group breakout sessions in this molecular biology course after the online transition. Past work has also identified several main barriers to student success in online courses, including lack of student motivation and interaction with peers [16-17]. There has been limited work examining student barriers in the context of the COVID-19 pandemic (e.g. see [18]), and most previous work on student barriers has focused on courses that were designed for and taught fully online. Our work thus seeks to identify if students perceived the same barriers to their learning in an inquiry-based molecular biology lecture and lab following the transition to online learning in the context of the COVID-19 pandemic. Finally, while past work has studied student learning in online science labs [e.g. 19-20], we are unaware of any previous work that examines how the shift to online instruction in an inquiry-based lab partway through a semester impacted student self-efficacy.

Methods

Course context and study population

Our work analyzes student perceptions in a predominantly first-year molecular genetics course at a private R2 institution in southern California that shifted online partway through the spring 2020 semester. To characterize the student population in these courses, we collected limited demographic information in our survey; responses were anonymized and de-linked from student names for this study. Response rates on the surveys were high both semesters (spring 2019: 156 of 177 students, 88.1% response rate; spring 2020: 139 of 157 students, 88.5%). This work was deemed exempt by the Chapman University Institutional Review Board.

Students taking this course in the spring are mostly life science majors (71.8% of students in spring 2019 and 74.1% in spring 2020) or enrolled in our 2+3 pre-pharmacy program (25.0% in spring 2019 and 18.7% in spring 2020), where students complete two years of undergraduate courses before transitioning to a three-year accelerated Doctorate of Pharmacy degree. The majority of students in spring are first-year students (76.9% in spring 2019 and 72.7% in spring 2020), with most of the remaining students in their second year of college (12.2% in spring 2019, and 20.9% in spring 2020). Approximately three-quarters (75.6% in spring 2019 and 73.88% in spring 2020) of students self-identified as female in our survey, reflecting our institution's skewed gender distribution of students.

Students have typically only taken one previous semester of introductory biology prior to this course since this is the second course in the introductory biology sequence for these majors. The course includes a lecture component taught by one of two instructors (the authors of this paper) and a lab component taught by the lecture instructors or by other full- or part-time faculty. There were three lecture sections of the course in both spring 2019 and 2020, with the same instructor teaching two of the three sections both years and roughly even enrollment across the sections.

Both the lecture and lab components of this course were fully in-person in spring 2019 and started in-person in spring 2020. The lecture component relied heavily on active learning, including frequent think-pair-share exercises, formative assessments such as polls, and inquiry-based breakout sessions where students were challenged to think critically about data or novel scenarios [e.g. see 21-23]. The lab, similarly, was a semester-long exploratory project where students extract DNA from a plant, amplify and clone a gene from their sample, and then sequence and analyze the results [24]. This inquiry-based lab incorporated multiple scientific practices, where students were challenged to interpret data at repeated points throughout the project and make decisions based off the data, were unaware of the results before doing the experiments, and had ownership over their own samples that they worked with the entire semester [25]. After the transition to remote learning in spring 2020, both the lecture and lab continued with synchronous sessions; while attendance dropped, the instructors noted that most students were still attending live. The lecture continued to use many active learning techniques, including the use of breakout rooms in Zoom to facilitate small group inquiry-based activities and the polls feature of Zoom. The lab, meanwhile, transitioned to synchronous classes where the instructor focused on promoting conceptual understanding of the purpose of each step remaining in the semester-long project as well as analyzing data from past semesters, including doing a short bioinformatics module. Students were provided with results from past semesters to analyze in class and in their end-of-semester lab write-up. Due to the shutdown of campus and the abrupt transition, it was not possible to film any videos demonstrating the lab (with the exception of one video used by some of the instructors) and no simulations were used, though instructors continued to provide previously filmed pre-lab videos that explained key concepts.

Survey

Students were surveyed after the last day of classes in both spring 2019 and spring 2020 about their experiences; completion was incentivized by a small amount of bonus points, and surveys were closed before final exams were given. The same questions were asked in these surveys in spring 2019, when the semester was fully in person, and spring 2020, with half the semester occurring online, thus providing a unique perspective into how student perception may have changed about the lecture and lab course in spring 2020 due to the online instruction. While the course is taught in fall semesters as well, there are fewer students and a very different demographic make-up (e.g. most students who take the course in the fall are sophomores), so we opted to compare spring 2019 to 2020 given the much closer student demographic profiles in these semesters. The courses remained largely the same in structure between the semesters except for changes necessitated by the shift to online instruction and the disruption to the course schedule due to the transition.

Students were asked the following open-ended, free response questions on the survey; two of the questions were isomorphic between the lecture and lab components of the course:

1) **What do you feel most contributed to your learning in this class?** This question was targeted specifically for the lecture component of the course.
2) **What do you feel most contributed to your learning in this lab?** This question was targeted specifically for the lab component of the course.
3) **What do you feel were barriers to your learning in this class?** This question was targeted specifically for the lecture component of the course.
4) **What do you feel were barriers to your learning in this class?** This question was targeted specifically for the lab component of the course.

5) **In a teaching lab like this, do you feel comfortable or prefer experiments that are guaranteed to give you pre-determined outcomes or are you ok with exploratory experiments such as this? Why or why not?**

Analyses of survey data

Approximately 20% of the responses across both years were coded by one of the authors following an emergent coding strategy [26]. The codes were then shared with the second coder, who reviewed the codes and independently coded the same responses. Disagreements were discussed until consensus was reached, and then one coder coded the remainder of the responses. Given the emphasis on identifying major themes from student responses and any change in these themes, codes that had fewer than ten responses in both spring 2019 and spring 2020 were excluded from the analysis for the first four questions, though were included for the question asking about student preference for exploratory labs versus labs with pre-determined outcomes in order to fully capture the range of student preferences. Frequency of codes were compared between years with a Chi-squared test or Fisher's exact test (for codes that were only found in one of the years) with a post-hoc Bonferonni correction.

Results

Student perceptions of supports and barriers to learning in lecture

Students identified several main areas that contributed to their learning in the lecture portion of the course; these categories largely remained the same between spring 2019 and spring 2020 (table I). The most common response in both spring 2019 and spring 2020 were students citing the breakout sessions, groupwork, and activities in class (24.3% and 23.7% of all codes in spring 2019 and 2020, respectively). There was one area that showed significant increases between spring 2019 and 2020: the percent of overall codes that indicated the lecture recording contributed to their learning increased from 0% in spring 2019 (when lectures were not recorded) to 4.9% in spring 2020, when online lectures were recorded. In contrast, fewer students reported reading the textbook as something that contributed to their learning (8.1% to 2.0% of codes from 2019 to 2020), the only category that saw a significant decrease from 2019 to 2020.

In contrast, there were marked differences in what students reported as barriers to their learning in the lecture portion of the course (table II). Nearly a third (27.7%) of responses indicated online learning as a barrier; while most students did not indicate the reason for why they perceived online learning as something that inhibited their performance, this was the most common response in spring 2020. The second most common response was related, with 8.8% of responses indicating that it was more challenging to engage online with small groups or the whole class. Neither of these categories were present in spring 2019. The percent of responses that cited a lack of motivation also dramatically increased (0.5% of all codes in spring 2019 to 11.2% in spring 2020). Two other categories (difficulty of the course, and the style of the exams with higher-order cognitive questions) saw small but significant decreases between spring 2019 and 2020.

Student perceptions of supports and barriers to learning in lab

There were no significant changes in the factors that students self-identified as contributing to their learning in the lab portion of the course between spring 2019 and spring 2020 (table III). In both 2019 and 2020, the most common response was that specific lab assignments were helpful (22.8% and 24.3% of all codes in 2019 and 2020, respectively), with the second most-common response citing the instructor (13.9% and 12.2% in 2019 and 2020, respectively). There were increases in the number of students who cited attending supplemental instruction (SI) sessions, where an undergraduate who has previously taken the class leads a weekly review and problem-solving session (from 3.2% to 10.8% of responses in 2019 and 2020, respectively) and instructor office hours (5.7% to 10.1%), though neither were significant. In contrast, there were major changes in what students self-identified as barriers to their learning in the lab between 2019 and 2020 (table IV). The most common barrier that students cited in 2020 was the inability to complete the hands-on aspects of the lab (37.5% of codes), which was not cited in 2019 given that the entire semester was in-person. The second most common self-identified barrier in 2020 was online learning (18.9%), another category that was not present in 2019. There was also a decrease in the frequency of student responses that cited the wording of the provided lab manual (16.0% to 3.6%), although the lab manual was not changed between semesters.

Student preferences of exploratory versus cookbook labs

Students in both 2019 and 2020 overwhelmingly preferred exploratory, inquiry-based labs as opposed to cookbook labs with pre-determined outcomes (74.6% and 76.4% preferring exploratory labs in 2019 and 2020, respectively; table V). Despite the transition to online learning, there was no significant change in the proportion of students who either preferred the exploratory labs nor those that stated they preferred cookbook labs (15.8% in spring 2019 and 23.0% in spring 2020). Interestingly, there were also no significant differences between the reasons provided by students as to why they preferred exploratory or cookbook labs. In both 2019 and 2020, the most common category of responses (26.5% and 29.7%, respectively) were students who cited that they preferred exploratory labs due to the realistic nature of the labs that reflected authentic scientific practices. The second and third most frequently cited reasons for preferring exploratory labs were that students enjoyed the process of having to think and analyze data more critically in an exploratory, inquiry-based lab than a cookbook lab (12.7% and 12.8% in 2019 and 2020, respectively) or that they viewed an exploratory lab as more interesting and exciting (13.8% and 10.1% in 2019 and 2020, respectively). The most common reason provided by students who preferred cookbook labs with pre-determined outcomes was that it would be easier to know what the outcome should be or to check their answers to a known standard in cookbook labs (8.5% and 14.9% in 2019 and 2020, respectively).

Discussion

Student supports and barriers to learning in lecture

These results provide a unique view into how students perceive an inquiry-based introductory molecular genetics course and the corresponding exploratory, inquiry-based lab both before and after the transition to online learning in spring 2020. Interestingly, breakout sessions remained the most frequently cited factor that contributed to student learning in spring 2020, with no decrease in perception from the previous year, suggesting that such small-group activities can be effectively transferred from an in-person to online setting without a change in student perception. Despite this, there was a significant increase in students who reported that engagement was a barrier in spring 2020, consistent with past literature showing that lowered engagement and diminished opportunities for social interactions in online courses can hinder student learning and their perceptions of learning [27-28]. The increase in students reporting engagement as a barrier in spring 2020 may be due to the randomized breakout groups we used in online lecture classes in spring 2020, while students were able to work with their chosen groups during in-person classes. The lack of familiarity with breakout group partners may thus have contributed to this decrease in perceived student engagement, a hypothesis consistent with having far fewer students report online engagement as a barrier in the lab portion of the course, when students were still able to work remotely with their same lab partners even after the transition to online learning.

In addition, fewer students reported the textbook as a resource that helped them learn from 2019 to 2020; similarly, fewer students reported that the lab manual being confusing was a barrier in 2020. It is unclear what may have caused these changes; it is possible that lower student motivation (as discussed below) resulted in fewer students reading the textbook and lab manual regularly, that students felt less need to read the book or lab manual given that they now had access to lecture recordings, or that fewer students had access to the textbook and lab manual following the transition to online learning (e.g. if they had relied upon the university library for accessing the book or did not bring the textbook or lab manual home with them given the abrupt nature of moving home). The only other significant change in what students perceived as contributing to their learning in lecture was for recordings of the course lectures; this is unsurprising given that in-person courses were not recorded, meaning that these recordings were a new resource only available for online instruction.

In addition to students citing the issues with engagement, many students also reported that having courses online was a barrier to their learning in both lecture and lab. Most students who did so did not provide insight into what aspect of online learning they found challenging, and future work is needed to elucidate the exact factors contributing to these negative student perceptions. However, one contributing factor that may be related is motivation, which has been shown to be a major barrier to student learning in online courses [27, 29-30]. Our results were consistent with past work (e.g. [18]), with a significant increase in students citing a lack of motivation in spring 2020. One student wrote that "staying motivated [with online learning] was particularly difficult. Going to [in person] class gave me a routine wherein I'd wake up at least an hour and half before class to get to school and the preparation for that jump started my day. Without that [in online learning] it was just me waking up 2 minutes before class, changing the location of where my laptop was positioned, so that I wouldn't just get tired. Also, I know myself and I know that I function better in class rather than on an online format. That in itself made it difficult to work online." This theme was echoed throughout the responses, with many students stating that they were having much more difficulty motivating themselves to participate in class and study in an online setting as compared to when classes were in person, or citing personal and technological barriers as dampening their motivation. We also speculate that the university's decision to allow students to switch to a pass/no pass grading scheme up until the last day of the semester may also have lowered motivation for students who previously were motivated by this extrinsic factor [30-31]. Finally, it is interesting to note that fewer students reported that the difficulty or rigor of the class was a barrier in spring 2020, with fewer students also stating that the higher-order questions on the exam were a barrier. These changes may be an artifact of the nature of open responses, when students may have written other barriers they perceived as more significant, or may be influenced by the university's decision to allow students to switch all classes to pass/no pass for the semester.

Student supports and barriers to learning in lab

Interestingly, there were no significant changes to what students perceived as most helpful to their learning in the lab portion of the course, despite the transition to online learning. Like with lecture, however, there were marked shifts in what students perceived as barriers to their learning in lab. The most frequent barrier cited in 2020 was the lack of ability to perform the hands-on aspects of the lab. Even though instructors focused more on conceptual understanding of lab techniques and data analysis and shifted away from assessing specific techniques, students still reported that the lack of completing the lab prevented them from fully grasping the concepts. "It was difficult to understand the labs without actually performing the steps," one student wrote, while another concurred, writing that "the only barrier I felt was the transition to online. With this transition, we were no longer able to perform labs, and physically performing the labs helped me understand what was going on." These responses indicate a disconnect between instructors' expectations and students' perceptions of the lab; we did not anticipate that not performing the lab would be such a significant barrier, given the decreased emphasis on mastering lab techniques in the online setting. In addition, many of the steps of the lab project that were discussed online were similar to steps that students had completely previously; for example, students had already completed a genomic DNA purification using column chromatography and had run and interpreted two PCR gels. Given this, we believed that students would be able to visualize similar techniques like plasmid purification from a bacteria and running and interpreting restriction enzyme digest gels. However, these data indicate that students viewed the lack of ability to physically conduct the labs as a barrier to their learning. Consequently, we will implement simulations and videos of the labs in future iterations of this lab that are taught online, and additional work is needed to assess the impact of these simulations and videos on student perceptions of learning in the inquiry-based lab.

Students prefer exploratory, inquiry-based based labs over cookbook ones

Despite these barriers reported by students, most students still preferred an inquiry-based exploratory lab over a cookbook lab with pre-determined outcomes. Students provided different reasons for why they preferred such exploratory, inquiry-based labs; these responses reflect some of the benefits that have been reported for course-based undergraduate research experiences (CUREs) and other inquiry-based labs [32-34]. For instance, the most common response was that students felt the exploratory lab was more realistic than a cookbook lab with pre-determined outcomes and reflected authentic research better than a cookbook lab. One student from spring 2020 wrote that “I like these exploratory experiments, as it gives us an opportunity to truly be a real researcher scientist, and it allows us to utilize critical thinking to come up with expected outcomes, and trace down sources of error if problems do arise. This is more of a real-world setting, and it could help when doing laboratory research in the future.” Other students mentioned similar feelings of validation and increases in self-efficacy, which have been reported to be benefits of CUREs and inquiry-based labs [35-36]. Students also reported that they preferred exploratory experiments due to having to analyze data and think critically more than they would have in a cookbook lab. "[Exploratory experiments] teach you a lot more about how to analyze all the different possible outcomes of your data and makes you do much more critical thinking when analyzing your results. These are important skills to have in any scientific field," one student wrote. Similarly, students also reported that they preferred exploratory experiments since they would be more interesting, would have to analyze different results and outcomes that varied from group to group, or that they would learn more in such a lab than a cookbook lab. "I am ok with experiments like this because it allows us to learn very in depth about one thing, versus pre-determined outcome labs are fairly surface level, in my opinion," one student wrote. "Because we are not graded on accuracy, we can instead really focus on actually conducting interesting experiments like this and learning about them in depth." Another commented that "I think it is good to have exploratory experiments because you can learn a lot from them. In the real world we are not always going to get what we want, so these types of experiments challenge you." These categories of responses also align with characteristics and benefits of CUREs and inquiry-based labs, which are known to lead to greater student learning and excitement [25].

These responses indicate that most students are self-reporting benefits in an inquiry-based lab with no change in student preference even with the transition to online learning, despite the barriers reported due to the online learning. While further work is needed to determine the impact of this online transition on student learning and self-efficacy as well as what these impacts would be if the lab course had been online for the entire semester, these results are promising and hint that the spring 2020 lab course that was half online may still have promoted the same benefits to student self-efficacy and led to the same increased excitement about inquiry-based labs and authentic research as compared to if the lab was completed in-person.

Limitations

There are several limitations to this study, which was done as a *post-hoc* retrospective analysis. First, the responses are from a single course at one institution and may not be representative of all students and classes. Given the limited scope of the study, responses could be heavily influenced by specific instructor or course attributes. Second, the survey data from 2020 did not ask students to clarify whether their responses were referring to the in-person or online aspects of the course; for example, some students may have responded that breakout sessions were very helpful to their learning and might only be referring to the in-person breakout sessions or the ones online, and not both. Despite these limitations, this study is one of the first to examine student perspectives of the transition to online learning in spring 2020 in an inquiry-based lecture and lab, and is one of the only studies we are aware of that incorporates student survey data from identical questions asked in a prior semester without online learning to provide baseline student perspectives in the course prior to online learning. We also characterize perceived student supports and barriers for synchronous lectures and labs that rely on frequent small group activities and inquiry-based teaching. Finally, our study provides valuable insights into how students view an inquiry-based lab, and how such perceptions largely did not change even when students were not able to complete the remainder of their project in lab in spring 2020.

Implications for biology and biochemistry instructors

These results provide several implications for biology instructors in lecture and lab courses. First, these data demonstrate that it is possible for instructors in synchronous online courses to continue using some active learning techniques without seeing a decrease in student perceptions of these activities. Second, student responses highlight the need for instructors to take deliberate steps to promote engagement among students; allowing the same breakout groups each time and providing time for community building may be beneficial. Third, instructors should be aware of the many challenges that students are facing when learning remotely, including a decrease in motivation and increases in stress and anxiety [2-3, 18], and can take steps to encourage intrinsic motivation of students and reduce student stress [31, 37]. We also find that students appreciated having highly structured courses, in line with past reports that more structured courses promote greater learning [38-39]. Students reported that having regular formative assessments, such as problem sets and discussion questions, as well as having supplemental instruction led by undergraduates who had previously taken the course, were highly beneficial to their learning, and instructors can promote additional structure in their courses and add in frequent, low-stakes formative assessments and practice resources for students [38-39]. Finally, these results indicate that instructors of online lab courses should consider adding in simulations or videos and not rely solely on discussions of the concepts behind different lab techniques, given the high frequency of students reporting that not doing the hands-on components of the lab was a barrier to their learning.

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Table I. Student perceptions of what helped them learn in the lecture component of the course. Significance is indicated with an asterisk. Note that since codes with fewer than 10 responses in both years were excluded, the percent of codes does not sum to 100%.

Category name	Definition	Number of responses that fell under this category in spring 2019 (percent of codes)	Number of responses that fell under this category in spring 2020 (percent of codes)
Instructor	Mentioned the instructor specifically or specific attributes about the instructor	6 (2.9%)	12 (5.9%)
Supplemental instructor	Mentioned the supplemental instructor (SI) or SI sessions	38 (18.1%)	27 (13.3%)
Breakout sessions	Mentioned breakout sessions, group work, or activities from in class	51 (24.3%)	48 (23.7%)
Examples/practice	Mentioned specific examples or case studies from class, or doing practice problems in class	12 (5.7%)	11 (5.4%)
Textbook	Mentioned reading the textbook	17 (8.1%)*	4 (2.0%)*
Problem sets and homework	Mentioned doing problem sets and other assigned homework	25 (11.9%)	37 (18.2%)
Recording	Mentioned recordings of in-class lectures	0 (0%)*	10 (4.9%)*
Office hours	Mentioned attending the instructor's office hours	9 (4.3%)	22 (10.8%)

Table II. Student perceptions of barriers to learning in the lecture component of the course.

Significance is indicated with an asterisk. Note that since codes with fewer than 10 responses in both years were excluded, the percent of codes does not sum to 100%.

Category name	**Definition**	**Number of responses that fell under this category in spring 2019 (percent of codes)**	**Number of responses that fell under this category in spring 2020 (percent of codes)**
Difficulty	Mentioned difficulty or rigor of class	14 (7.5%)*	2 (1.2%)*
Time	Mentioned limited student time outside of class for studying and preparing for the class, workload of other classes that would limit this time, or conflicts with attending office hours, etc.	25 (13.3%)	10 (5.9%)
Online learning	Mentioned online class or online learning as a barrier	0 (0%)*	47 (27.7%)*
Exam style	Mentioned challenges with the exam style of higher-order questions	26 (13.8%)*	2 (1.2%)*
Critical thinking	Mentioned had challenges with critical thinking, or not being able to apply concepts to a situation	16 (8.5%)	5 (2.9%)
Resources	Mentioned a lack of resources or not enough resources for preparing for assessments	10 (5.3%)	4 (2.4%)
Pace	Mentioned pacing of course or content delivery, or amount of content covered	13 (6.9%)	8 (4.7%)
Concepts	Mentioned that concepts were challenging or confusing, or did not understand the concepts	14 (7.5%)	4 (2.4%)
Engagement online	Mentioned harder to engage online, whether in breakout groups or with the class	0 (0%)*	15 (8.8%)*
Motivation	Mentioned lack of motivation or procrastination	1 (0.5%)*	19 (11.2%)*
None	Stated that they had no barriers	15 (8.0%)	11 (6.5%)

Table III. Student perceptions of what helped them learn in the lab component of the course. None of the differences were significant between 2019 and 2020. Note that since codes with fewer than 10 responses in both years were excluded, the percent of codes does not sum to 100%.

Category name	Definition	Number of responses that fell under this category in spring 2019 (percent of codes)	Number of responses that fell under this category in spring 2020 (percent of codes)
Instructor	Mentioned the instructor specifically or specific attributes about the instructor	22 (13.9%)	18 (12.2%)
Supplemental instructor	Mentioned the supplemental instructor (SI) or SI sessions	5 (3.2%)	16 (10.8%)
Lab manual	Mentioned reading the lab manual	12 (7.6%)	5 (3.4%)
Problem sets and homework	Mentioned doing assignments for lab	36 (22.8%)	36 (24.3%)
Pre-class videos	Mentioned instructor-made pre-class videos	21 (13.3%)	11 (7.4%)
Office hours	Mentioned attending the instructor's office hours	9 (5.7%)	15 (10.1%)

Table IV. Student perceptions of barriers to learning in the lab component of the course. Significance is indicated with an asterisk. Note that since codes with fewer than 10 responses in both years were excluded, the percent of codes does not sum to 100%.

Category name	**Definition**	**Number of responses that fell under this category in spring 2019 (percent of codes)**	**Number of responses that fell under this category in spring 2020 (percent of codes)**
Time	Mentioned limited student time outside of class for studying and preparing for the class, workload of other classes that would limit this time, or conflicts with attending office hours, etc.	12 (7.7%)	4 (2.4%)
Online learning	Mentioned online class or online learning as a barrier	0 (0%)*	30 (17.9%)*
Lab manual	Mentioned lab manual was confusing or unclear	25 (16.0%)*	6 (3.6%)*
Concepts	Mentioned that concepts were challenging or confusing, or did not understand the concepts	19 (12.2%)	10 (6.0%)
Not doing lab	Mentioned challenging to not actually do the lab or perform the hands-on aspects of lab techniques	0 (0%)*	63 (37.5%)*
Overlap	Mentioned lack of overlap between lecture and lab	10 (6.4%)	7 (4.2%)

Table V. Student preferences about exploratory labs versus labs with pre-determined outcomes. None of the differences are significant between spring 2019 and 2020.

Category name	Definition	Number of responses that fell under this category in spring 2019 (percent of codes)	Number of responses that fell under this category in spring 2020 (percent of codes)
Exploratory – interest/excitement	Mentioned exploratory experiments are more satisfying, interesting, and/or exciting but did not provide a reason why	26 (13.8%)	15 (10.1%)
Exploratory – outcomes	Mentioned appreciated analyzing results that were not necessarily pre-determined or would be different from group to group	15 (7.9%)	10 (6.8%)
Exploratory – realistic	Mentioned exploratory experiments felt more realistic or reflective of authentic science; includes validation of student as scientist	50 (26.5%)	44 (29.7%)
Exploratory – process	Mentioned exploratory experiments made student think more or have to analyze more, i.e. highlighted the process of exploratory experiments	24 (12.7%)	19 (12.8%)
Exploratory – novel	Mentioned discovering new things or felt like it was novel	6 (3.2%)	0 (0%)
Exploratory – learning	Mentioned exploratory experiments contribute to greater learning	14 (7.4%)	16 (10.8%)
Exploratory – other reason	Mentioned exploratory and gave another reason that did not fall in category above	6 (3.2%)	9 (6.1%)
Pre-determined – check outcomes	Mentioned pre-determined outcomes since it is easier to know what the outcome would be or check answers	16 (8.5%)	22 (14.9%)
Pre-determined - grading	Mentioned pre-determined labs would lead to easier grading or higher scores	2 (1.1%)	1 (0.7%)
Pre-determined – failure	Mentioned preferred pre-determined since group got negative or unsatisfying results, or classmates did	4 (2.1%)	2 (1.4%)
Pre-determined – stress	Mentioned preferred pre-determined since less stressful	1 (0.5%)	4 (2.7%)

Pre-determined – other	Mentioned pre-determined lab for another reason that did not fall in a category above	7 (3.7%)	5 (3.4%)
No preference / other	Did not state an explicit preference or stated that had no preference	18 (9.5%)	16 (10.8%)
Total exploratory		141 (74.6%)	113 (76.4%)
Total pre-determined outcome		30 (15.9%)	34 (23.0%)