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Undergraduates' Experiences with Online and in-Person Courses Provide Opportunities for Improving Student-Centered Biology Laboratory Instruction

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Biology laboratory courses with hands-on activities faced many challenges when switched to online instruction during the COVID-19 pandemic. The transition back to in-person instruction presents an opportunity to redesign courses with greater student input. Undergraduates in an ∼350-student laboratory course were surveyed about their preferences for online or in-person instruction of specific laboratory course components. We predicted that students who have taken a virtual laboratory course prefer keeping some of the components online. We also hypothesized that their preferences are affected by their experience with online-only or with both online and in-person instruction. The results showed that students would like to move the laboratory component and group meetings back to in-person instruction, even if they never experienced college-level in-person courses. Also, many components, including the lectures, exams, assignment submission, and office hours are preferred to be held online. Surprisingly, students who have only taken online courses would rather give group presentations in person, while those who experienced both online and in-person instruction were undecided. Group presentations were the only component where the preference of the two groups significantly differed. Self-assessed learning gains showed that students performed very well in both the online semesters and the in-person semesters. Therefore, the preferences measured in this study were likely developed based on students' future expectations and personal gains, and not only on their metacognitive decisions and academic performances. This study provides considerations for redesigning components of laboratory courses to be more student-centered after the pandemic.

KEYWORDS online learning, face-to-face instruction, inquiry-based laboratory, undergraduates, pandemic pedagogy, student-centered teaching, metacognition.

INTRODUCTION

Metacognition, understanding our own process of thinking and learning, has been a frequently discussed pedagogical element in undergraduate education (1–4). However, students are rarely given a choice in how they learn, because the instructors develop the course curriculum and components. The unexpected transition to online learning at the beginning of the COVID-19 pandemic caught many instructors and students off-guard with the need to reevaluate how teaching and learning takes place in online (OL) and face-to-face (F2F) learning environments. While the transition was especially challenging for laboratory, field, and studio courses where students practiced hands-on activities (5–9), there are many lessons that can be learned from the transition from F2F education to OL classes and from the transition back to F2F teaching. While decisions about the course components are mostly made by instructors, these transitions present an opportunity to redesign courses with greater student input.

Biology laboratory courses are often designed to be hands-on and student-centered, using active learning methods (10) to teach students laboratory skills, science literacy, and scientific knowledge that they will use as upperclassmen in microbiology, molecular biology, and genetics courses or in research laboratories during their scientific careers, even after graduation. Active learning is known to be a very effective teaching method (11–15), and laboratory courses provide the perfect learning environment for implementing these pedagogical techniques. Well-designed OL teaching laboratories can be very successful, and they can outperform F2F instruction in medical laboratory programs (16), in physics laboratories (17), or by virtually teaching skills in microbiology (18) and in chemistry (19). The cookie cutter laboratories, where every student conducts the same exercises, are often replaced by inquiry-based laboratories (20–22), where students design their own experiments with somewhat known

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TABLE 1
Learning outcomes developed for the course used in this study

By the end of the course, students will be able to
1. Design hypothesis-based experiments, choose appropriate statistical test(s), analyze data, and interpret results.
2. Demonstrate mastery of lab techniques and scientific methods that can be applied across biological systems and scales.
3. Find and evaluate relevant scientific information using appropriate library tools.
4. Effectively contribute to work within their research groups and reflect on the ethics, benefits, and challenges of collaborative work.
5. Use discovery science to explore patterns in nature and apply accuracy and precision to the scientific process.
6. Apply fundamental biological information to increasingly novel and complex situations.
7. Author and produce scientific content using digital, oral, visual, audio, and written communication formats.

outcomes and learn the scientific process through these guided experiments or replaced by Course-Based Undergraduate Research Experiences (CUREs), where students create new knowledge in a realistic research laboratory environment (23–26).

Laboratory courses teach much more than just how to use a microscope or plate bacteria. They teach students how to think and act like scientists, how to make observations, come up with hypotheses, design and execute experiments, collect, and analyze data, communicate results through paper writing or other media (27–30). The transition to OL learning and the transition back to F2F environment did not equally impact all these course components and learning objectives, and students and instructors may have preferences for what to transfer back to F2F instruction from their OL teaching and learning experiences. Certain components, such as scientific writing through peer-review (28), case studies (31), or forums and debates (32) using web-based response systems (33) more easily lend themselves to be adapted for an OL learning environment, than other components such as how to use lab equipment.

Since students experienced the transition from OL to F2F instruction themselves, they should not only be passive spectators, rather active participants of the transition back to postpandemic F2F instruction, to help establish the "new normal." The objective of this study was to identify which components the students would prefer experiencing OL and which components they would restore from F2F courses. We predicted that students who experienced OL learning for at least one semester would not like to return to the prepandemic laboratory course exactly as it was, and that they would instead prefer keeping some of the components of the course online. We hypothesized that these preferences would differ between those students who experienced both OL and F2F learning formats and those who had taken only OL classes in college.

METHODS

This study was conducted in a large, inquiry-based introductory biology laboratory course that uses modules in microbiology and in ecology to teach students how to think and act as scientists (7, 27, 28, 33). This semester-long laboratory course was developed for students in the biological sciences major with learning outcomes focusing on scientific and laboratory skills (Table 1). The course has two components each week: a laboratory period (up to 3 h long) and a lecture (up to 50 min long). The maximum course enrollment is 432 students (24 laboratory sections with a maximum of 18 students in each section). The course is designed in a modular format using scientific inquiry. The two research modules cover the evolution of antibiotic resistance in bacteria and the nutrient limitation of algal population growth. In F2F instruction, the 50-minute-long, in-person live lectures used a variety of active learning techniques, such as think–pair–share exercises (10), case studies (31), forums (32) and interactive audience participation using a web-based response system (33). The laboratory sections teach hands-on laboratory skills, peer review in scientific writing (28), statistical reasoning and the scientific process with the focus on critical thinking, problem-solving and transferable skills (27).

As a response to the COVID-19 pandemic, the authors made a midsemester emergency switch from F2F to OL instruction (Spring 2020) and then developed the course to be completely OL for the following two semesters. The fully OL components included both synchronous online lectures (weeks 1 and 2) and prerecorded lectures (weeks 3–11). All 24 laboratory sections were held synchronously online using a video conferencing program (Zoom, San Jose, CA.) for 12 weeks, with a maximum of 18 students in each lab, and were continued to be taught by laboratory instructors and undergraduate teaching assistants (34). The prerecorded lecture component included formative assessment using a web-based response system (33), and the laboratory sections maintained active learning techniques through a variety of methods, including think-pair-share (10) and breakout rooms (7).

Students enrolled in this laboratory course in the two most recent prepandemic completely F2F semesters (Spring 2019 and Fall 2019) and in two OL semesters during the pandemic (Fall 2020 and Spring 2021) were anonymously surveyed using the Qualtrics online survey tool (Qualtrics, Provo, UT) in the last lab of the semester. Participation was voluntary, questions could be skipped or ignored, and no compensation was given. The survey response rate for the Spring F2F semester was 364/378 students (96%) and for the Fall F2F semester was 368/392 students (94%). For the two OL semesters, the response rates were 319/361 students (88%) and Spring was 239/307 students (78%). Students were asked to retrospectively estimate their level of knowledge or skill level with specific scientific practices before and after

TABLE 2
Student retrospective estimations of skill and knowledge gain in a face-to-face (F2F) and in an online (OL) teaching format in an introductory biology course, as anonymously provided by students in Spring 2019 and Fall 2019 (F2F) and in Fall 2020 and Spring 2021 (OL)[a]

Objective	Format	Semester	Before (retrospective) (mean ± s.d.)	After (mean ± s.d.)	Gain	n
How to perform serial dilutions, use a micropipette, sterile technique, spectrophotometer.	Fall	F2F	3.43 ± 1.21	4.39 ± 0.69	0.96	367
		OL	2.97 ± 1.3	4.1 ± 0.77	1.13	319
	Spring	F2F	3.31 ± 1.29	4.39 ± 0.73	1.08	364
		OL	2.95 ± 1.26	3.98 ± 0.81	1.03	237
How to use a microscope and a hemocytometer.	Fall	F2F	2.69 ± 1.2	4.21 ± 0.72	1.52	369
		OL	2.68 ± 1.23	4.04 ± 0.78	1.36	319
	Spring	F2F	2.93 ± 1.24	4.31 ± 0.76	1.38	362
		OL	2.55 ± 1.25	3.91 ± 0.81	1.36	237
Skills in science communication (literature search, technical writing, poster prep).	Fall	F2F	3.12 ± 0.97	3.86 ± 0.72	0.74	367
		OL	2.88 ± 1.09	4.25 ± 0.63	1.37	319
	Spring	F2F	3.12 ± 1.05	3.96 ± 0.71	0.84	364
		OL	2.86 ± 1.11	4.33 ± 0.64	1.47	237
How to generate figures and use statistics to analyze data.	Fall	F2F	2.79 ± 1.14	3.9 ± 0.74	1.11	368
		OL	2.66 ± 1.14	4.12 ± 0.65	1.46	319
	Spring	F2F	2.82 ± 1.26	3.97 ± 0.8	1.15	364
		OL	2.82 ± 1.14	4.15 ± 0.62	1.33	237

[a]Students could select from a 5-point scale ranging from "No knowledge" (coded as 1) and "Masterful knowledge" (coded as 5). The sample size (n) represents the number of students who responded to that question.

taking the course on a 5-point scale ranging from "Masterful knowledge" to "No knowledge." Additionally, the overall course scores, used to determine final letter grades, were de-identified and calculated on a 100-point scale. Since all assessments were developed to carefully align with the learning outcomes (Table 1), the overall course grades are reflective of students meeting or not meeting the learning objectives in the course.

During the most recent OL semester (Spring 2021), when it seemed likely that the course would return to in-person instruction in the fall, students were asked about their preference for an OL or F2F option for each of several components of the course (electronic or hardcopy assignment submission, online or in-person exams, using a chat window or raising a hand in lecture to participate, office hours, group meetings, group presentations, lab sections held via videoconferencing or in person and flexible assignment deadlines versus fixed deadlines). Students were asked about the lecture options, comparing the previous two main lecture delivery methods in the course: "In the fall, this course will likely return to in-person instruction. If labs meet in person, what do you recommend for the weekly lecture component?" Students could choose either, "Live, in-person lecture in an auditorium at 9:05 AM once per week with active learning components, such as talking with students seated near you and answering poll questions," or "What you did this semester: Prerecorded lectures with poll questions released once per week and available to watch for several days." Academic year, prior research experience, and previous experience with OL and F2F courses (to identify whether they have taken college courses only OL or both OL and F2F) was also collected voluntarily.

Comparisons of the preferred learning environment for each course component was conducted. The preferences between the learning environment experience groups (OL-only versus both OL and F2F) were also analyzed. Chi-squared tests using a binomial function to compare two proportions, with the null hypotheses that one learning environment was not favored over the other, were applied to survey data (35) using the statistical software R (36).

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RESULTS

Estimating learning gains and meeting learning objectives

When students were asked to retrospectively estimate their skills and knowledge before and after taking the course, learning gains were similar in the two F2F semesters than in the two OL semesters (Table 2). Students perceived that they mastered laboratory skills, science communication and statistics, as effectively in the OL than in the F2F semesters. End of the semester grades were high both in OL and F2F semesters, showing that students have met the learning objectives, regardless of the learning environment. Median score was 97.17 at the end of the Spring OL semester ($n = 307$) and 96.11 at the end of the Spring F2F semester ($n = 376$). Students performed very well

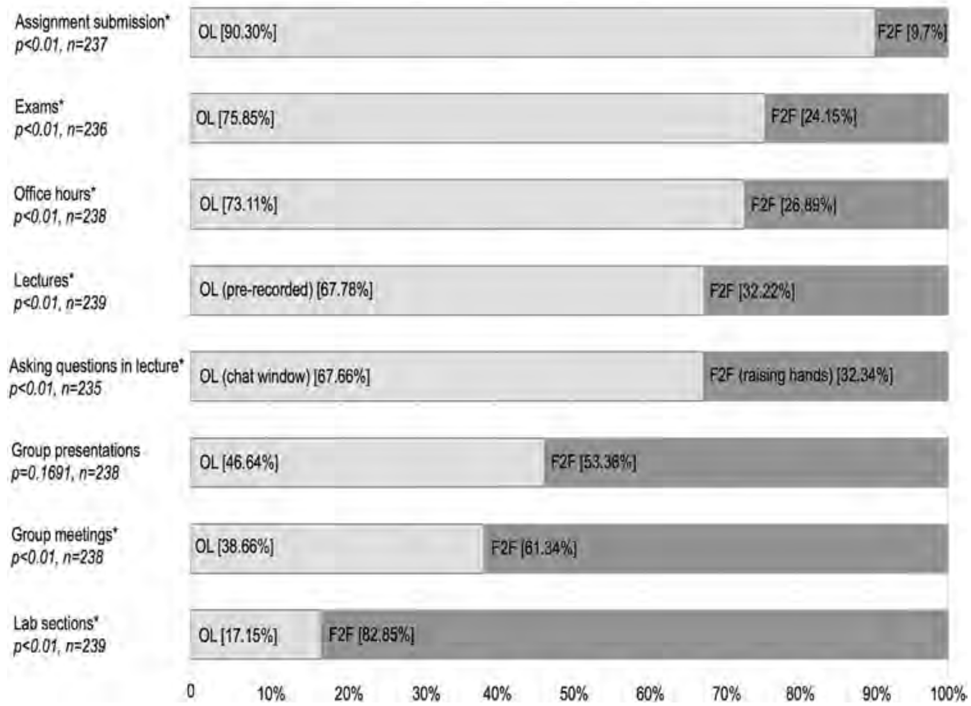

FIG 1. Student preferences regarding keeping course components online (left) or moving back to face-to-face instruction (right). The question categories can be found on the *y* axis, while percentage of the students choosing either online (OL) or face-to-face (F2F) options is on the X-axis. Statistically significant preference is indicated by an * next to the category name. Sample size (n) and significance level (α = 0.05) are also listed. The exact percentage of the students who preferred each category is listed in the bar plot for each choice. The wording of the categories in the figure is simplified and shortened from the survey.

in the Fall semesters too, completing the Fall OL semester (median = 96.72, N = 362) and the Fall F2F semester (median = 95.16, N = 392) with high grades.

Student preferences of OL versus F2F course components and their experience with OL versus F2F learning environments were also collected during the last OL spring semester. In this OL semester, among the responders (N = 239), 74% were freshmen, 18% sophomores, 5% juniors, and only 2% seniors, and most of the students in the class (77%) had not worked in a research laboratory at a university prior to the semester. Most students were also experienced in both OL and F2F learning environments (78.15%), while only 21.85% had only taken OL college courses. Those students who had taken OL only courses were all (100%) freshmen.

Lecture component

When students were asked whether they would like to attend a F2F lecture with active learning components or receive prerecorded lectures with embedded questions like they did during the OL semester they had just completed, most of the students (X_2 *[1, N = 239]* = 59.0, *P* < 0.01) chose prerecorded (67.78%) over F2F lectures (32.22%). When it came to student preferences for how they could ask questions during lectures, most prefer using a "chat window for asking questions during lectures" (67.66%) rather than "raising [your] hand during lecture to ask a question" (32.34%) (X^2*[1, N = 235]* = 57.2, *P* < 0.01).

Lab activities

There was a strong preference for F2F lab sections (82.85%) compared to OL lab sections (17.15%) (X^2*[1, N = 239]* = 203.6, *P* < 0.01). While students more strongly preferred "In-person research group meetings outside the classroom" (61.34%) over "Zoom research group meetings outside the classroom (for designing experiment, preparing poster, etc.)" (38.66%) (X^2*[1, N = 238]* = 23.6, *P* < 0.01), preference was evenly split for "Live group presentations" (53.36%) versus "Zoom group presentations" (46.64%) (X^2*[1, N = 238]* = 1.8, *P* = 0.1691; Fig. 1). When the presentation preference data were analyzed at the learning experience level (OL versus both OL and F2F), 61.54% of *OL only* students would prefer F2F group presentations (X^2*[1, N = 52]* = 4.6538, *P* = 0.0309), but the larger group that had taken *both OL and F2F* courses had no preference (X^2*[1, N = 186]* = 0.01, *P* = 0.9170), masking the response from the OL-only students when data from both groups were combined.

Office hours and Assessment

Office hours, exams, and assignment submission method were preferred by students to remain OL (Fig. 1). Nearly three-quarters of students would like to keep office hours online ("Zoom office hours," 73.11%; "live office hours," 26.89%) ($X^2[1, N = 238] = 99.8$, $P < 0.01$). When it comes to assessment in the form of exams, students would rather be assessed online, even in a F2F learning environment. There is a strong preference for taking "online exams" (75.85%) as opposed to "in-person exams" (24.15%) ($X^2[1, N = 236] = 124.0$, $P < 0.01$). A supermajority of students would also prefer "online assignment submission" (90.30%) over "handing in printed assignments" (9.7%) ($X^2[1, N = 237] = 304.6$, $P < 0.01$) and receiving flexible deadlines on assignments (85.65%) as opposed to fixed deadlines (14.35%) ($X^2[1, N = 237] = 238.1$, $P < 0.01$).

DISCUSSION

Virtual classrooms can be very successful if they are well designed (16, 18, 37), but such course design can take several years to implement (37). Instructors did not have that time scale to develop an OL course when they needed to switch to emergency remote instruction due to the COVID-19 pandemic (38–40). However, learning how to manage the virtual classroom, and the transitions between OL and F2F learning environments created an unexpected opportunity for instructors to improve higher education (38, 41, 42). How to tap into this opportunity should be based on conversations between the students and the instructors, identifying the preferences and best practices for all stakeholders (7, 43). Some of the components that were used in OL teaching may be kept after the return to F2F instruction, especially if they support students' learning and academic performance.

In this study, we found that students who experienced OL instruction for at least one semester would like to keep some of the teaching components online even after the course returned to F2F instruction. We predicted that these preferences differ among those who experienced both learning formats (OL and F2F) and those who took only online classes so far in college; however, we found a difference in student preference only for group presentations. The other course components were consistently preferred to be kept either OL or F2F regardless of the students' previous learning experiences.

Student preferences alone should not dictate how instruction is delivered. Instructors should also consider whether learning goals are likely to be achieved before deciding on which pedagogical practices to employ. In this study, students in OL semesters did not perceive that they learned less than those in F2F semesters. In fact, for two course objectives, science communication and statistics, students' perceptions of learning gains were somewhat higher in OL semesters compared to F2F semesters. While the direct comparison of some of the individual assessment scores between OL and F2F semesters is difficult, the end of the semester scores clearly indicated that students performed very well in both learning environments and met the learning objectives. Makransky et al. (2016) demonstrated that virtual lab simulations can prepare students for microbiology lab activities as effectively as F2F lab sections (18), while others provided evidence that students who used simulated physics equipment (17) or computer-based simulation labs (44) performed just as well or even better than those students who learned the same skills in an F2F environment.

Despite the fact that student performed well in both OL and in F2F semesters, they had strong preferences for some components to be kept online or held in-person. Therefore, students' preferences between the OL and F2F components are likely based on a broad variety of criteria, not only on how well they mastered the course material and what grade they received in the course. In the next sections, we summarize student preferences, discuss possible reasons for these preferences, and make recommendations for the return to F2F instruction.

Keeping lectures online and returning to in-person laboratory sections

The course in which the students were surveyed for this study has both a lecture and a laboratory component (27). When F2F, lectures were to be simultaneously attended by all enrolled students (>350), but after transitioning to OL instruction, the lecture component of the course mostly took the form of asynchronous prerecorded presentations that included interactive questions. Our students recommended that we keep this prerecorded OL format for lectures once the course returned to F2F instruction. Anecdotal commentary from students in end-of-semester evaluations of teaching revealed that this preference was in part influenced by the flexibility of lectures being asynchronous, the ability to pause and rewatch recordings, and the convenience and comfort of choosing where to watch them. There are additional pedagogical reasons for instructors to follow these recommendations, especially when deciding between prerecorded or live OL lectures. Large lectures with hundreds of students in attendance are challenging to manage synchronously online, even with the help of teaching assistants (34). For example, it may be difficult to monitor activity in the chat window of video conferencing software, and programs like Zoom may have limitations on the number of breakout rooms (45) and can be slow when moving large number of students into these rooms. Providing lectures as recordings is a way for instructors to avoid these potential pitfalls. Additionally, providing lecture recordings along with synchronous laboratory sections is like a "flipped" or inverted classroom design (46), where students engage with the material (prerecorded lecture) and then attend the laboratory sections to build on that knowledge and discuss it (47, 48). Furthermore, recorded lectures need not be less engaging than live lectures, as they can have active learning components, like embedded web-based formative assessment questions (33), that can increase student engagement with the lecture material (49).

Although our students recommended that the lecture component remain online, they also recommended that the laboratory sections return to an F2F format. This was a strong preference by both those who had never taken F2F college courses and those who had taken both OL and F2F courses. There may be a variety of reasons for this preference. For example, 77% of the surveyed students had not had experience working in a research lab yet, therefore it is possible that they worried that the lack of hands-on experience with laboratory equipment would negatively affect their ability to apply to jobs or volunteer opportunities in research laboratories. Students had great academic success in both OL and F2F semesters, but they are often concerned about not only their grades, but also about how to learn and how to maximize their time investment in a course (50). Student expectations can also be misaligned with their experiences, especially if they are freshmen (51).

In addition, the 3-h-long laboratory sections can be exhausting for the students and instructors alike. Long online interactions can drain peoples' energy, decrease interest in the material, and create "Zoom fatigue" (52, 53). Students may also feel in an OL laboratory environment that they do not develop the best instructor-student and student-student relationships. Belonging, often defined as feeling accepted and supported by instructors and peers, was found to be especially important for freshmen in the classroom (54), and it can have a strong impact on motivation and achievement (55). Students face many challenges in an OL learning environment and it can be difficult, although not impossible to develop an equitable and inclusive OL laboratory (7). So, while students may successfully master laboratory skills online, not being able to build connections with peers and instructors in person and participating in long, draining, OL laboratory sessions may contribute to their preference for F2F laboratories.

Group meetings and presentations

Biology courses often use group projects or create teams, where peers need to develop experiments, solve problems, or give presentations together (37, 56–58). Since students prefer to return to F2F laboratory sections, it is understandable that they prefer meeting with their group mates F2F outside the classroom too, probably for reasons like those discussed above. However, these group projects often culminate in a group presentation and, while those students whose learning experience includes both F2F and OL classes did not have a preference, students with only OL learning experience significantly preferred the F2F group presentations. It is important to recognize that students who experienced only OL group work and OL group presentations in college would rather take the chance of the unknown experience of F2F group presentations. There could be many explanations for this phenomenon. The presenting students giving a seminar style talk about their research project, or a poster presentation of their results may have faced the same challenges that instructors faced when students did not turn their cameras on in the classroom (7). This lack of interaction online may have disproportionately impacted these freshmen who have only taken OL courses until now, and their need for F2F engagement and belonging (54) could be a main reason why they recommended to move presentations offline.

Assessment

During the transition to emergency remote learning many instructors needed to modify how they assessed students (37, 43). Students participating in this study preferred flexible assignment deadlines over fixed deadlines, preferred taking OL exams instead of F2F exams, and preferred submitting assignments electronically rather than printing them. Student's preferences suggest that both formative and summative assessment techniques need to be reevaluated when courses return to the F2F learning environment, and instructors should continue using some of the technologies they benefited from during OL semesters. For example, Learning Management Systems allow online submission of assignments and make grading or peer-review easier (28). Additionally, flexible deadlines can be set to remove some pressure from the students, but they may require that students have good time management skills.

Large biology classes often use formative assessment tools to engage audiences (7, 33, 59–61). In an OL learning environment, engagement and formative assessment tools like polling software, Google Drive, Google Jamboard, Zoom chat windows, and other technologies are available for instructors (7, 37). These technologies often provide anonymity to the students who asked questions and shared opinions during the class. Moving these sharing methods to F2F environments may have positive benefits, including creating a more equitable experience for students who do not want to perform in front of the entire class (62). This is perhaps why students preferred using a chat window over raising their hand in lecture to participate. While many of these formative assessment methods have been used already in F2F active learning classrooms, the emergency transition to OL learning raised the salience of the value of these web-based engagement opportunities.

Keeping office hours online

Attending office hours can improve academic performance (63) and students would like to keep office hours online. This has many positive accessibility implications, as students do not need to find and access the physical location of the office hours, allowing them to conveniently connect online when they just have a few minutes between classes. Students who are in quarantine, sick, or have limited mobility can more easily access the instructor during online office hours. Online communication, such as instant messaging, online chat or Zoom has been shown to foster strong interactions between instructors and students during office hours (64–66). Laboratory instructors in this study anecdotally reported that attendance at office hours had increased after moving to online teaching.

CONCLUSIONS

As it has been shown in the past decade with the rise of active learning, inquiry-based laboratories, and CUREs, biology laboratory education is continuously evolving. As they return to in-person teaching, instructors and course designers need to consider what components they continue to successfully use online. Students should be partners in these decisions rather than passive spectators. Students may develop their preferences based not only on academic performance but using a combination of factors, including previous personal experiences, future expectations, perceptions, and metacognitive learning strategies. Regardless of whether they had taken only online courses before or both online and in-person courses, our students preferred OL lectures but F2F laboratory sections. They would also like to keep OL office hours, and OL exams, but prefer to meet with their research group F2F to work on group assignments. Keeping some online components is not necessarily bad pedagogy, as it may increase attendance at office hours, allow more accessibility, promote equity, accommodate flexible schedules, and decrease stress. It may, however, also decrease the perception of belonging, make networking harder, and make student-student and instructor-student interactions more challenging. Students should most benefit from a healthy balance of both OL and F2F components to create a better learning environment. Assessments of skills and comprehension of course content should still be the primary factors used to make pedagogical decisions. However, as our study shows, student-centered pedagogy includes bringing the students into the conversation to be able to support their needs and preferences, while maintaining a course structure that helps achieving the course learning outcomes.

As college campuses return to F2F instruction following the pandemic, we recommend taking a student-centered approach that considers students' preferences when weighing the pedagogical costs and benefits of keeping some components of the course in an OL format.

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