TEACHING INNOVATIONS

Updating anatomy and physiology lab delivery: shifting from a paper-based to an online lab instruction platform, just in time for a global pandemic

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Abstract

This paper describes how an anatomy and physiology laboratory class transitioned from a paper-based lab to an online learning platform that updated the curriculum to rely more on face-to-face small group collaboration and peer teaching. Student perceptions of the new format were positive, but halfway through the transition a global pandemic challenged the new instruction method. The face-to-face curriculum had to be adjusted to a virtual format that lacked in-person interaction between the instructor and the students. This switch to virtual labs had an adverse effect on both student perception and student performance in the second half of the semester. Our observations underscore the importance of creating an interactive community when teaching virtually.

collaborative learning; online learning systems

INTRODUCTION

The role of technology in teaching physiology laboratories has been a topic of discussion since the very first issue of Advances was published in 1989 (1). The first computer data acquisition systems appeared around 1990, replacing paper-and-ink physiographs, and today many institutions use some form of computer data acquisition in their student laboratories. Major textbook publishers have created online laboratory simulations, and academic institutions have supported faculty development of virtual experiments that can be shared online (cf. Ref. 2). However, is creating a technology-based laboratory an effective way to teach?

The original goal of this study was to assess student engagement and enjoyment of an online learning platform as an additional learning tool for a two-semester combined anatomy and physiology (A&P I and A&P II) laboratory class. The first phase of the study, in the 2018–2019 academic year, had students using computer data acquisition hardware and transducers (PowerLab from ADInstruments) to collect physiological data, but their handouts were posted online, and they completed laboratory reports after class in a traditional paper report format. In the second year (academic year 2019–2020), students in the first semester of the course (2019 A&P I) continued using this format, but in the second semester (2020 A&P II), the data acquisition hardware and transducers were incorporated into an online integrated learning platform (Lt, ADInstruments). The laboratory classes still focused on in-person physiological and anatomical experiments and activities, but the new online learning platform required more interaction by the students. The interaction took the form of required individual prelaboratory assignments as well as group quizzes at the start of the laboratory session plus guided small group collaboration with peer teaching during the activities. Data analysis and report write-up were incorporated into the learning platform and were completed by students working collaboratively during the in-person laboratory session.

Halfway through the 2020 A&P II semester the onset of the novel coronavirus global pandemic forced all our classes to go online, requiring the students to complete the last two laboratories of the semester in a completely virtual format. By the end of the semester, we had data to compare two face-to-face laboratories with and without integration of the online learning program and two different laboratories that went from face-to-face instruction on paper in 2019 to completely virtual instruction in 2020.

The rapid shutdown of in-person teaching around the world renewed what has been a long-time debate: can traditional face-to-face (F2F), hands-on laboratory experiences be adequately replaced with computer simulations, remote data acquisition (students operate equipment from a distant site), and other types of virtual or simulated laboratory activities? Whether virtual laboratory classes are as effective as in-person classes is difficult to answer because of a myriad of confounding variables, ranging from what the educational objectives are for the laboratory to the many different modalities of virtual laboratory activities (3, 4). In 2015, Brinson (5) published a review and synthesis of 86 post-2005 studies that compared learning outcomes from virtual and remote laboratories to
learning outcomes in traditional hands-on F2F laboratories. In his analysis, 89% of the studies concluded that virtual laboratories were as effective or more effective than in-person laboratories. The question of efficacy has been supported by more recent papers as well (6–8). Unfortunately, the outcomes used in most of these studies were related to acquisition of content knowledge as assessed by tests and quizzes, which leaves open the question of whether virtual laboratories are as effective for teaching noncontent competencies such as teamwork, problem-solving skills, and acquisition of hands-on research skills such as pipetting.

A second question to be answered about the relative value of face-to-face and virtual laboratories is student perception. In one study by Brockman et al. (9), medical students experienced some of their microbiology laboratory as online simulations rather than as hands-on experiments. When asked about the ideal format, almost 90% of the respondents felt that having some in-person laboratory experience was important. In an introductory biology course for nonmajors (10), where students participated in both F2F laboratories and a virtual laboratory, student comments indicated that for the virtual exercises, they missed working in person with peers as well as the opportunity to ask questions of the instructor and get feedback as they were working on the activity. Rowe et al. (11) recorded nearly identical comments in a study that included laboratory classes in biology, chemistry, and physics. An instructional design that has been well-received by students is a blended format, where students prepare for the in-person laboratory by doing online prework that often includes a simulation or other virtual experiment (12–15).

In early 2020, when the coronavirus pandemic shut down colleges and universities worldwide and sent students home to learn remotely, the physiology teaching community involuntarily became participants in an experiment that saw traditional F2F student laboratories forced into a virtual online format. This paper outlines the transition of a year-long A&P course from paper-based laboratories to laboratories using an online learning platform to pandemic-induced remote laboratory instruction with the new online learning platform. Student feedback and laboratory assessment performance are included for the entire transitional period.

### MATERIALS AND METHODS

This project was approved by the institutional review board at Centenary College, Scholarship of Teaching and Learning Umbrella 2018–2020, Biology Department, Protocol No. 18-002. The broad nature of the project approved by the Institutional Review Board includes all data presented in this paper.

#### Study Design

Participants in this study were junior and senior undergraduate life science or psychology students at Centenary College of Louisiana, a small liberal arts institution. They were enrolled in a two-semester sequence of human anatomy and physiology (A&P I and A&P II). Each 16-wk course consisted of 2.5 h/wk of lecture, split into two 75-min sessions, plus one 3-h laboratory/wk. Students were required to complete and pass the first semester of the sequence (A&P I) before enrolling in the second semester course (A&P II). The A&P I course was taught in the August-December semester, and A&P II was taught in the January-May semester.

The A&P I course began with anatomical terms/directions and a review of select cellular and molecular biology topics. It then covered systems organization, tissue histology, and the nervous, musculoskeletal, and cardiovascular systems (Table 1). The second semester (A&P II) content included continuation of the cardiovascular system, followed by the respiratory, renal, digestive, endocrine, and reproductive systems. In the 2018–2019 cohort, all of the laboratories used paper handouts to direct the students through the laboratories (Table 1). Some activities used data acquisition hardware (DAQ) and physiological transducers (PowerLab from ADInstruments, www.adinstruments.com) and virtual microscopy (VM), as shown in Table 1.

#### Table 1. Overview of course content and lab activities covered in the year-long anatomy and physiology course

| Lecture topics | Anatomy & Physiology I: 2018 A&P I and 2019 A&P I | Anatomy & Physiology II: 2019 A&P II and 2020 A&P II |
|----------------|-----------------------------------------------|---------------------------------------------------|
| Anatomical Terms and Directions | Blood/Lymphatic System | Cardiovascular Effects of Exercise (DAQ) |
| Cellular and Molecular Biology Review | Respiratory System | Lung Anatomy and Histology (VM) and Spirometry (DAQ) |
| Homeostasis/Control Loops | Gas Exchange | Diving Response (DAQ) |
| Systems Organization | Urinary System | Kidney Anatomy and Histology (VM) |
| Tissues and Histology | Fluid and Electrolyte Balance | Digestive Anatomy and Histology (VM) |
| Nervous System (CNS, PNS, and Senses) | Digestive System | Urinalysis Lab |
| Musculoskeletal System | Metabolism | Endocrinology Lab |
| Cardiovascular System | Endocrine System | Reproductive Anatomy and Histology Lab (VM) |
| Laboratory topics | | |
| Anatomical Terms and Directions | Cardiovascular Effects of Exercise (DAQ) | |
| Tissue Histology (VM) | Lung Anatomy and Histology (VM) and Spirometry (DAQ) | |
| CNS Anatomy (sheep brain dissection) and Histology (VM) | Diving Response (DAQ) | |
| Tactile Receptors (student subjects) | Reflex Arc (DAQ; 2020 only) | |
| Sheep Eye Dissection | Kidney Anatomy and Histology (VM) | |
| Skeletal System Anatomy | Digestive Anatomy and Histology (VM) | |
| Muscle Anatomy | Urinalysis Lab | |
| Muscle EMG (DAQ) | Endocrinology Lab | |
| Cardiovascular Anatomy | Reproductive Anatomy and Histology Lab (VM) | |

VM, virtual microscopy; DAQ computer data acquisition hardware; CNS, central nervous system; PNS, peripheral nervous system.
Students coming into the A&P II course were familiar with the data acquisition equipment and virtual microscopy from the experiments in A&P I. In the laboratory, students worked in groups of two to three students, assigned by the instructor, and students remained in the same laboratory groups for the entire semester. Table 2 describes the laboratory activities compared in this study. For the 2019 and 2020 A&P II laboratories, all activities except two 2020 laboratories were completed in person during the regularly scheduled laboratory time (Table 2). During all F2F laboratory classes, the instructor (J.A.S.) reviewed the laboratory with the students and then allowed the students to progress through the protocol with their laboratory group members, working mostly independently from the instructor. The instructor and a teaching assistant were available for assistance throughout the laboratory period, and the instructor checked in with every group at points to review tricky concepts or help with data analysis. The diving response laboratory required more step-by-step instruction due to its more complex set-up and data collection protocols.

Table 2. Description of compared laboratory activities

| Lab Activity                                | Description                                                                                                                                                                                                 |
|---------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Diving response (2019 and 2020)             | Students measure finger pulse heart rates before and during a simulated dive with face immersion into a tub of cold water. Adapted from Ref. 16.                                                                     |
| Cardiovascular effects of exercise (2019 and 2020) | Students monitor participants’ heart rate at rest and after 2 min of exercise (jumping jacks).                                                                                                           |
| Reflex arc (2020)                           | Students elicit the patellar tendon reflex and investigate factors that influence it. (New in 2020. Data acquisition equipment integrated with the online learning platform.)                                       |
| Endocrinology (2019 and 2020)               | The activity tests student understanding of endocrine pathways and feedback loops by asking them to interpret the results of experiments where normal and castrated rats were injected with unknown hormones from hypothalamic-pituitary-endocrine gland pathways (17). |
| Reproductive anatomy and histology (2019 and 2020) | Students work in groups (F2F lab) to review male and female reproductive anatomy and histology using virtual microscopy for histology plus physical anatomical models. Group work was optional in the virtual 2020 lab. |

F2F, face-to-face.

Table 3. Comparison of lab protocols in 2019 and 2020 labs

| Lab Activity                                | 2019 F2F Paper-Based Protocols                                                                                                         | 2020 F2F Online Learning Platform                                                                                                                                 |
|---------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Diving response, cardiovascular effects of exercise | BEFORE LAB Handouts posted a week in advance. Students not required to read them.                                                       | BEFORE LAB Online prelab assignment due before lab. Questions relate lecture content to the lab activity.                                                                           |
|                                             | IN LAB Paper handouts in lab provided background, methods, and data tables. Instrutor demonstrated and led the entire lab step-by-step.    | IN LAB In-lab online quiz completed in groups. Quiz results used to guide prelab discussion.                                                                                               |
|                                             | Students in groups completed a written lab report with data analysis. Reports were due the following week.                               | Instructor reviewed lab set-up but groups worked independently to complete the activity.                                                                                                   |
|                                             | **2019 F2F Paper-Based Protocols**                                                                                                      | Lab report was submitted online before leaving the lab.                                                                                                                                    |
| Endocrinology                               | BEFORE LAB Copies of paper handouts posted online a week in advance. Students not required to read them.                               | **VIRTUAL** 2019 Lab materials moved into online learning platform. Students not required to complete any prelab work.                                                               |
|                                             | IN LAB Instructor led the entire lab. Group activity: review of endocrine pathways Groups given different case studies to diagnose           | Students individually completed the endocrine pathway review, analyzed three different case studies, and wrote a report.                                                              |
|                                             | Groups present their case study and conclusions to the class.                                                                             | Students had the option of working together but submitting separate reports.                                                                                                               |
|                                             | **VIRTUAL** 2019 Lab materials moved into online learning platform. Students not required to complete any prelab work.                   | Instructor was available via Zoom during the regularly scheduled lab session for questions and a lab walk-thru.                                                                        |
| Reproductive anatomy and histology          | IN LAB Paper handouts guided students through virtual histology slides and anatomical models of the male and female reproductive organs. | VIRTUAL Students individually viewed virtual microscopy slides, filled in tables, and answered questions about the slides.                                                           |
|                                             | Handouts included questions for the students to complete and/or tables to fill out.                                                       | Students had the option of working together but submitting separate reports.                                                                                                               |
|                                             | Students took a graded oral quiz over the histology slides with their group before leaving the lab.                                       | Instructor was available via Zoom during the regularly scheduled lab session for questions and a lab walk-thru.                                                                        |

F2F, face-to-face.
The project began with the 2019 cohort of A&P II students, which served as the paper-based laboratory baseline. Students who had completed A&P I the previous semester were not required to take the A&P II course, and as a result the numbers of students taking the A&P II class were small (2019, n = 14; 2020, n = 19). Four activities were compared between the 2019 and 2020 A&P II cohorts: diving response, cardiovascular effects of exercise, endocrinology, and reproductive anatomy and histology. The reflex arc laboratory added in 2020 had no parallel for comparison in 2019.

The 2019 and 2020 A&P II cohorts differed in the way the laboratory material was presented (Table 3). For the 2019 A&P II cohort, the laboratory followed a traditional approach: all materials were in the form of instructor-written paper handouts that included the laboratory protocol, data tables, and instructions for the laboratory report. Students were not required to review the written laboratory material before the laboratory period (although the laboratory handouts were posted a week in advance on the course website). All physiology-focused laboratories were designed using guided inquiry methodology. Students worked together to formulate a hypothesis and design an experiment based on the described physiological parameters. In the laboratory, students used data acquisition hardware and transducers to collect human data. They completed the data collection and analysis portion of the laboratory in groups of two to three students, and each group wrote a laboratory report after class and turned in a paper copy the following week. The students’ grades on the laboratory activity were determined fully by the submitted group laboratory reports.

The 2020 A&P II laboratory protocols were revised when the instructor (J.A.S.) received a Teaching Career Enhancement Award from the American Physiological Society and used the funding to purchase student access to the Lt online learning platform (ADInstruments) for the 2020 A&P II class. This platform integrates the previously used data acquisition hardware and transducers with ready-to-use online lessons containing background information, questions, equipment instructions, hardware settings, and data analysis tools. Instructors have the ability to edit the lessons by adding or removing content as needed to better fit their course’s particular learning objectives. Lessons can be completed individually or in small groups, and many question types can be set up with hints, immediate feedback, multiple tries, and automatic grading. The lessons used in the 2020 A&P II semester were edited to better align the laboratory activity content with the course learning objectives.

The revised laboratory syllabus using the new platform required students to complete prelaboratory assignments that placed the anatomical and physiological concepts covered by the laboratory activity in the context of the course lecture material. The goal of the online prelaboratory assignments was to ensure that the students reviewed the relevant lecture content before the laboratory. The assignments also served as formative assessment and gave the students an opportunity to note and correct any content misconceptions before the laboratory session. The questions on basic A&P concepts were presented in multiple formats, including image or concept map labeling, multiple choice, table completion, and free response. The students were able to check and correct their answers as they progressed through the material. The online assignments were due before the start of the laboratory session.

At the beginning of the F2F laboratory class, students worked in their assigned groups to complete an online quiz incorporated into the learning platform. The group quiz was in multiple choice format and focused on physiology content of the laboratory activity. After all groups completed the timed quiz, the instructor used the quiz results to clarify points of confusion with the class and to answer content questions about the activity. The instructor then briefly reviewed the laboratory set-up before allowing the students to work in groups to complete the activity. The online activity included questions that students answered as they worked. The software compiled student answers and data analysis into a group laboratory report that was submitted before the students left the laboratory. The students’ grades on the laboratory activity were determined by a combination of points from the individual prelaboratory assignment, in-laboratory group quiz, and final group report.

The Impact of COVID-19

The 2020 semester was interrupted in March by a complete switch from F2F laboratories to online delivery of laboratory activities due to the COVID-19 pandemic. As a result, the last two laboratories of the semester were run completely online and in an asynchronous format. This was an institutional requirement to assist with schedule interruptions or technology issues now that students were completing the work off-campus. The platform and laboratory setup for the virtual laboratories were familiar to the students, but the virtual format did not require student collaboration on the laboratories (group work) or instructor interactions. The students could complete the laboratories as an individual effort and on their own time. Students were allowed to collaborate in groups if they wanted, but they turned in individual laboratory reports by a predetermined deadline. The instructor was available via Zoom during the regularly scheduled laboratory session for student questions and a laboratory walk-thru. About one-third to half the class attended these sessions. Other students completed the assignments on their own or with self-selected classmates working virtually.

Student Perceptions of the Learning Platform

Student feedback was collected via online surveys. For the 2019 A&P II course, most of the questions related to the lecture portion of the class and only a single question asked students to note their favorite and least favorite laboratories and explain. All students in the course (n = 14) completed the survey. At the end of the 2020 A&P II semester, students were asked to complete an online survey for feedback on the laboratories and their use of the online learning platform. Students were asked to read a set of statements and rank each statement on a Likert scale where 1 = strongly disagree, 2 = somewhat disagree, 3 = neutral, 4 = somewhat agree, and 5 = strongly agree. They also had an opportunity to write comments about their rankings. All students in the class (n = 19) completed the survey.

Statistical Analysis

All statistical tests were calculated using JASP software, version 0.14.1. For the comparison of 2020 A&P II laboratory
report grades, a one-way repeated measure ANOVA was used due to the same subjects (students) being represented in each independent group. Post hoc analysis included a Bonferroni correction to assess differences among the laboratory score means. The ANOVA output table generated by JASP includes the calculation of eta-squared ($\eta^2$), which is a measure of effect size determined by calculating a ratio of the sum-of-squares ($\text{SS}_{\text{treatment}}/\text{SS}_{\text{total}}$).

For the comparison of student scores on Lab 8 with how the students chose to complete the laboratory, an independent-samples $t$ test was selected. The data were also analyzed using a Shapiro-Wilk test of normalcy (online completion, $P = 0.55$; alone completion, $P = 0.33$). $P > 0.05$ indicates that the data follow a normal distribution supporting the use of the parametric test. Effect size was calculated on the significant findings using Hedges’s $g$ unbiased effect size calculation (18). This test was selected due to the small and dissimilar sample sizes of the groups. For interpretation of effect size, the greater the score was, the greater the difference between groups and the greater the effect.

For comparison of student scores on the laboratory exam sections, a nonparametric statistical test was selected (Wilcoxon rank-sum test, also called the Mann Whitney $U$ test). Both the cardiovascular effects of exercise (2019, $P = 0.04$; 2020, $P = 0.05$) and diving response (2019, $P = 0.01$; 2020, $P = 0.01$) data yielded significant results ($P < 0.05$) with a Shapiro-Wilk test of normalcy indicating that the data sets deviated from a normal distribution, which supports the use of the nonparametric test. All statistical results are reported within the corresponding results section.

## RESULTS

### Student Perceptions of the Learning Platform

In January and February of the 2020 A&P II semester, students completed laboratory activities using the online learning platform, shifting from paper-based laboratory handouts that they had used during the previous semester’s A&P I laboratories. As described in the MATERIALS AND METHODS, the new platform included individual prelaboratory assignments, in-laboratory group quizzes, and a different laboratory report format. The final two laboratories of the semester were completed in the virtual format. At the end of the semester, students were asked to complete an online survey for feedback on the laboratories and their implementation (Fig. 1). The students could include additional comments at the end of the survey. Student response rate was 100%.

Overall, students rated the new platform highly, found the laboratory activities to be fun and engaging and felt that the technology enhanced their learning (Fig. 1). The primary negative comments were that some experiments were boring, confusing, or difficult, especially in the virtual format (comments included in Table 4). Students were also asked to compare the A&P II laboratories with the addition of the learning platform to the A&P I laboratories without the learning platform:

- “[the A&P II labs] felt organized and easier to follow”
- “[the A&P II lab] questions made me think more too which is always good”
- “[the A&P II labs were] more organized and in depth and easier to use”
- “I felt like they [the A&P II labs] were a bit more spot-on to what was going on in lecture. I felt like they connected more [to the lecture].”

In addition to the general feedback, the 2020 A&P II students were asked to rank each laboratory activity on a scale of 1 to 5, with 5 being the highest ranked/most favorite. Scores were averaged and shown with select comments in Table 4. The two virtual laboratories, endocrinology and reproductive anatomy and histology, were ranked as the least favorite.

It is difficult to make an exact comparison between the 2020 “favorite” rankings and 2019 because student feedback for 2019 A&P II laboratories was less systematic and simply

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**Table 4.** The two virtual laboratories, endocrinology and reproductive anatomy and histology, were ranked as the least favorite.

| Statement | Likert Scale |
|-----------|--------------|
| I think the Lt online lessons and lab activities are a valuable learning activity. | 1 |
| The Lt in-lab activities were fun and engaging. | 2 |
| The Lt in-lab activities allowed me to practice applying course content to real-life physiological scenarios. | 3 |
| I think having questions other than multiple choice questions improved my mastery of the material. | 4 |
| The Lt online lessons and lab activities helped me retain information covered in this course. | 5 |
| The Lt online lessons provided a new and interesting way to review course material. | 1 |
| The guided questions throughout the lessons and lab activities helped me understand difficult material better. | 2 |
| The Lt online lessons and lab activities were easy to use and navigate. | 3 |

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**Fig. 1.** Student perceptions of the online learning platform as recorded by an online survey. At the end of the 2020 Anatomy and Physiology (A&P) II semester, students ($n=19$) were asked to complete a survey that asked for student feedback on the virtual learning platform (Lt) presentation of the lab activities. Students were asked to read a set of statements and then rank each statement on a Likert scale where 1 = strongly disagree, 2 = somewhat disagree, 3 = neutral, 4 = somewhat agree, and 5 = strongly agree.
Table 4. Student ranking and feedback of 2020 A&P II lab activities

| Lab                                      | Average Score | Student Comments                                                                 |
|------------------------------------------|---------------|----------------------------------------------------------------------------------|
| Diving response                          | 3.95          | So much fun!! How hands-on it was really made me learn the material. My favorite because it was honestly the most fun to do and watch others do. I think it was a great way for us to clearly see what happens in our body. It was also something that we never really think about our body doing, so it was cool to see that. |
| Reflex arc                               | 3.58          | I liked the way data was collected for this one, the equipment was really easy to get accurate data and not hard to collect. The Reflex Arc lab was my second favorite because it was also fun to do. Introducing the different variables that effect [sic] the reflex was really interesting, and it was cool to see it actually happening in front of us with the graphs to show it. |
| Cardiovascular effects of exercise       | 3.37          | This one was also engaging and fun. Since a lot of us are athletes I thought it was very neat to see how exercise effects [sic] our cardiovascular system. Lab f: The heart is cool! I think that this was a great way to think about how exercise can influence a lot of things. |
| Endocrinology (virtual)                  | 2.05          | This [lab] helped a lot with information retention for the test, but it was just complicated and hard and I got confused a lot. This was fun in some spots, but because it was online it was more challenging. The histology aspect was more challenging to properly learn online too. |
| Reproductive anatomy and histology (virtual) | 2.05        | It was very interesting and helped a lot with the material for the test, but it was just very long and seemed to be redundant. |

Students (n = 19) were asked to rank the 5 labs from their favorite (5 points) to least favorite (1 point). Average scores and representative comments are shown. The table lists the labs from most favorite to least favorite.

asked students to note their favorite laboratory and explain why in an online end-of-course survey. The favorite laboratories from the 2019 A&P II semester were the diving laboratory and the exercise laboratory, due mostly to their interactive nature and application of physiological topics. The 2019 endocrinology laboratory was also rated highly in the in-person, instructor-led format, with students favoring the problem-solving and application aspects of the laboratory. This is in sharp contrast to the same endocrine laboratory in the 2020 virtual format.

Selected student commentary from the 2019 A&P II laboratories is below:

- “I enjoyed diving response and the exercise lab the most because they were the most interactive.”
- “The diving response lab and exercise lab were some of my favorite labs probably because they were more physiology based and . . . required more thinking from us.”
- “I think my favorite lab although I struggled with it was the endocrinology lab with the rats….I enjoy solving some mysteries and I felt as if the diagnosing part of the lab was very helpful.”

Student Performance on Online Lab Assessments

The grades on the online laboratory assessments for the different 2020 A&P II activities are compared in Fig. 2. For the in-person laboratories (Labs 1, 3, and 4), the laboratory assessment grade had both individual effort (prelaboratory work) and group work (group quiz, data acquisition, analysis, and laboratory report). The laboratory report included data analysis and application questions that were completed during the laboratory activity. Labs 8 and 9 were completely online due to remote teaching requirements with COVID-19, with the prework and laboratory report grouped into one lesson that could be completed at any time. There were also no group quizzes. These two virtual laboratories were individual efforts, with group work and participation in the instructor-led virtual session optional but encouraged.

Overall, students performed better on the laboratory assessments that were completed in person with their laboratory groups or that were in a familiar format (virtual microscopy) than they did on the virtual endocrine laboratory, with means averaging more than 19 out of 20 possible points. The two virtual laboratories had lower means, although only Lab 8 endocrinology scores were significantly lower when compared to all other laboratories (repeated measure one-way ANOVA, $P < 0.001$ with Bonferroni post hoc test, $P < 0.001$; $\eta^2 = 0.51$). An $\eta^2$ of 0.51 indicates that 51% of the total variance can be accounted for by the treatment (laboratory activity). Overall, the solitary online format seemed to increase the perceived difficulty of the laboratories, as noted in the student comments (Table 4).

Interestingly, when the Lab 8 endocrinology report grades are separated based on how the students chose to complete the laboratory, there is a difference in the laboratory report scores (Fig. 3). Students who joined the interactive online laboratory session with the instructor performed better ($P = 0.009$, independent-samples t test, $n = 17$) on the laboratory assessment than students who completed the laboratory solely on their own. Effect size calculation (Hedges’s $g$) indicates that the groups differ by 1.45 SD, indicating a large effect. Two students who completed the laboratory together but separate from the instructor-led online session received individual scores of 17.0 and 16.0 out of a possible 20.0. The lower scores observed in students who chose to work completely by themselves highlight the role of the instructor as well as peer teaching (group work) in understanding difficult physiological concepts. However, it is also possible that the lower scores for students who completed the endocrinology assignment on their own may reflect stress and lack of motivation resulting from the sudden switch from normal college life to remote instruction.
The 2020 A&P II laboratory exam was administered online in 2020.

The most difficult virtual laboratory for the students was the endocrine laboratory, where students are asked to interpret the results of experiments in which normal and castrated rats were injected with unknown hormones (17). When this activity was conducted in a F2F setting, the instructor walked through all the hypothalamic-pituitary endocrine pathways and feedback loops with the students in a question and answer format, giving the students ample time to work through the pathways with their laboratory groups. She reviewed the relevant lecture material and gave them a chance to ask questions and clear up misunderstandings before they were given an unknown hormone problem to solve. The virtual platform version walked students through the same endocrine pathways, but unless the students worked together or attended the virtual instructor-led session, their performance on the laboratory report was not as good (Fig. 3). Student comments about the endocrine laboratory from the end-of-semester online written survey reflect the difficulty of working virtually:

This study began as an effort to evaluate student engagement and enjoyment of A&P laboratories after adding an online learning platform as an additional teaching tool. Near the end of the 2020 A&P II semester in which the learning platform was added, the COVID-19 pandemic required the remaining laboratories to go to a virtual format that continued to use the learning platform. The two laboratories that were required to go virtual were the easiest to transition because they did not rely on experiments where the students were physically connected to transducers. In addition, students were familiar with histology and using virtual microscopy from their first semester of A&P; so transitioning to the online format was not as difficult as it would have been if they had no previous histology experience. Physical anatomical models were missing from the virtual laboratories but were replaced with illustrations and labeling activities as part of the online version. Student comments (Table 4) indicated that the resulting online laboratory was too long and somewhat boring.

The two limitations to this study are the small number of students and the potential effect of student stress in 2020 from the COVID-19 pandemic and the new online-only learning environment.

DISCUSSION

This study began as an effort to evaluate student engagement and enjoyment of A&P laboratories after adding an online learning platform as an additional teaching tool.
“This was a really hard laboratory to understand and do on your own at home. It was interesting, but it took me a very long time and I was confused about some of the stuff.”

“This was just super confusing to do on an online platform and by yourself. And even when working with others over FaceTime it is difficult.”

These comments are in sharp contrast to student comments from the 2019 cohort, where the activity was done F2F with the instructor and students working in groups:

“My favorite was probably the Endocrinology. I enjoyed these because we got to learn information and then apply it immediately. I liked getting to use the information I had learned to diagnose a pathology.”

“My favorite laboratory out of all was the endocrinology because I really enjoyed the problem-solving/diagnosis feel of that laboratory.”

The preference for working hands-on with peers and instructor assistance has been noted in other studies comparing F2F laboratories with virtual or hybrid instructional models (9–11).

In terms of student perception, we found that students rated the interactive physiology laboratories highly, whether using paper handouts or the computer-based learning platform, although comments suggested they thought the online presentation was more organized. Student comments about the two virtual laboratories at the end of 2020 A&P II underscore the importance of instructor participation and group or collaborative work. The online formats of noncollaborative laboratories were not rated as highly and were perceived as more difficult or boring.

Student performance on the laboratory reports for the virtual laboratories also suffered, although students who attended the optional instructor-led online sessions fared better than students who chose to complete the activities by themselves. Student performance on summative assessments for the in-person instructor-led laboratory activities indicate no difference between students who used paper handouts and those who worked through the learning platform for F2F laboratory activity delivery. We were unable to compare the virtual 2020 laboratories to the paper 2019 laboratories because of significant changes to the format of the summative assessments.

One unanswered question is what would have happened to both student perception and performance if the earlier hands-on laboratories had gone virtual, the mode of instruction that is taking place at many institutions in the second half of 2020. Converting student-active physiological data collection laboratory experiments to distance learning is a challenge that people are tackling in different ways. In one format, the instructor and a subject perform the experiment in person and stream it live over Zoom. Bhaskar et al. (19) describe a method in which students observing a spirometry demonstration from home can analyze the graphs obtained by taking remote control of the instructor’s laptop.

A second option for data collection experiments is for the instructor to record the experiment and embed the recording into a learning platform for student viewing. In both models, students can be given data from the experiment to analyze. Our experience suggests that requiring students to work in virtual laboratory groups for the analysis will improve student learning and promote noncontent skills such as teamwork. If data analysis is done asynchronously, one way to minimize academic dishonesty is to give each laboratory group a distinct data set. This is easier if the instructor has access to student data sets from previous semesters of the F2F laboratories.

Another option for physiological data collection laboratories is to consider low-tech activities that meet the laboratory objectives and that the students can complete by themselves at home. Staircases can replace treadmills for exercise, and students can take their pulse manually or with the inexpensive finger pulse oximeters that many people purchased at the start of the COVID-19 pandemic. Students can collaborate and share data analysis in virtual groups that meet via Zoom, Google Meet, or other platforms, and the instructor can hold virtual office hours for students to discuss their results and data analysis.

The question of how much student stress influenced student performance on virtual laboratories at the end of the 2020 semester is difficult to answer. A survey of students at a large Texas university conducted in April 2020 after classes went virtual found that 71% of the students answering reported increased anxiety and stress, while nearly 90% reported difficulty concentrating (20). The new and unpredictable circumstances surrounding the move to online teaching in the spring of 2020 undoubtedly affected student learning. The literature on trauma-informed teaching (21, 22) indicates that effective teachers should monitor student well-being and provide emotional support to help students cope. The instructor for the 2020 A&PII class (J.A.S.) frequently and consistently communicated with the students about plans and deadlines using email and the school’s learning management system (Canvas). She also provided many resources on online learning, time management, and stress management to assist with the transition. Simple online surveys asked
students about accessibility to resources (internet, computer, etc.) and other concerns, such as health or family issues, that may have arisen during the transition to a new location. Students in the class were open and honest about their new, challenging circumstances and indicated that they appreciated the instructor’s concern. Three students reported having to take on a new job or family role; however, these students still fully participated in the course, including the virtual group laboratory sessions. Students who did not participate in the virtual group laboratory sessions reported no extenuating circumstance. The trusting relationship that the instructor had built with the students over the previous semester (or longer, due to the small department size) facilitated and almost certainly eased the sudden transition to virtual instruction.

The take-away from our involuntary transition to virtual laboratory delivery is that the social interactions of group work are important, as are in-person or synchronous sessions with the instructor where students can ask questions and clear up points of confusion. Although we are currently limited in our F2F gatherings, we can require students to work virtually in groups and to meet with us for laboratory review, both of which will help promote a sense of community despite the separation imposed by the pandemic.

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No conflicts of interest, financial or otherwise, are declared by the authors.

**AUTHOR CONTRIBUTIONS**

J.A.S. and D.U.S. conceived and designed research; J.A.S. performed experiments; J.A.S. analyzed data; J.A.S. and D.U.S. interpreted results of experiments; J.A.S. prepared figures; J.A.S. and D.U.S. drafted manuscript; J.A.S. and D.U.S. edited and revised manuscript; J.A.S. and D.U.S. approved final version of manuscript.

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