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Student Self-Efficacy and Satisfaction: A Comparative Analysis of Online and Onsite Versions of an Analog Electric Circuits Lab*

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We present the design, operation, and analysis of an online introductory-level analog electric circuits course. The course is an adaptation of a sophomore-level onsite course taught in its current form at the University of Maryland, College Park for a decade and has both a traditional lecture component and an active-learning laboratory component. We compare the expectations, attitudes, and performance of the students whose lab sections were online to those students who took the traditional onsite lab. The study was preformed across four sessions from the summer of 2020 through the summer of 2021 with a total of 111 students. The summer classes were 100% online, but the fall and spring semesters had a mix of onsite and online lab sections. A total of 34 students took the onsite version of the lab leaving 77 students in the online lab sections. Twenty-six percent of the students were female, Hispanic, or African American. The percentage of students passing the course was 88% both for the full cohort and for the underserved population. The percentage of online students passing the course was 92%. Student surveys probed the students' expectations, level of satisfaction, and self-efficacy and focus groups were conducted to help validate survey results. While onsite lab students had higher expectations and were more satisfied with their lab experience, the two cohorts reported similar feelings of self-efficacy. The post-course analyses helped to improve the online course from one semester to the next, but the quality of the interaction with the instructors and teaching assistants was found to have a significant impact on the students' responses.

Keywords: analog circuits; online education; laboratory; higher education

1. Introduction

An introductory electric circuits class is universal for electrical engineering and computer engineering students. An active-learning lab component to the class is generally considered an essential part of the circuits course. While the course content can vary from place to place, it generally includes the student learning objectives (SLOs) listed in Table 1, which are the actual SLOs we have for our course. The italicized SLOs are developed in the laboratory and the others are presented in the lecture.

The demand for online STEM classes has been gaining traction in the past few decades and has recently accelerated because of the COVID-19 pandemic. Several engineering lecture courses have been converted to online formats [1]. While these efforts have generally been considered successful, many students feel that the online offerings in STEM classes are not nearly equivalent to their onsite versions [2] and there is much room for improvement [3]. Several online engineering undergraduate lab courses have also been developed in recent years. The earliest online labs typically involved only simulations with electronic circuit software, while other online lab courses controlled the test and measurement equipment remotely [4–9]. One study found that students complained about the loss of hands-on learning, feeling that labs are best taught in front of the physical hardware [10].

Recently, electronic hardware has become available that facilitates active hands-on learning away from the classroom. The Arduino (introduced in 2005) [11], the BeagleBone (2011) [12], the Raspberry Pi (2012) [13], and other small computers have made it inexpensive and easy to program IOT devices from anywhere [14, 15]. Another important development has been the introduction of inexpensive electronic devices that connect to a computer via a USB cable and run software that allows one to take voltage measurements and display them on a screen that resembles an oscilloscope. These devices also have built-in power supplies and signal generators, and some have digital pattern generators and spectrum analyzers. Low-cost devices include the NI myDAC (2012) [16], the Red Pitaya (2013) [17], the NI Diligent Analog Discovery 2 (2016) [18], and the Analog Devices ADALM2000 (2017) [19, 20]. Students can often buy them at a discount. The Analog Discovery 2 (AD2) and the ADALM2000 have two oscilloscope channels, two signal generators, two power supplies (± 5V max) and 16 digital input/outputs. They both have software to control the interface

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Table 1. The Student Learning Objectives (SLOs) for the Introductory Analog Circuits Course

Identify common circuit components: resistors, inductors, capacitors, independent sources, diodes, transistors, and operational amplifiers (op-amps); understand the terminal relations and models that are used to describe the operating characteristics of these components.
Understand and systematically apply basic circuit laws governing voltages and currents (Kirchhoff's Laws).
Analyze linear AC/DC steady-state circuits.
Use basic circuit techniques (i.e., Nodal analysis, superposition, parallel and series combinations, equivalent transformations, Thevenin and Norton equivalents) to analyze and design linear circuits.
Understand circuit transients and calculate responses for first and second order circuits.
Understand elementary concepts of electronic circuits such as op-amps and their circuit models.
Analyze and design multiple op-amp circuits.
Use basic test and measurement equipment necessary to evaluate the performance of simple electric and electronic circuits.
Understand basic limitations, inaccuracies, and tolerances of the test equipment, components, and procedures.
Design circuits with efficient reliability and cheaply achieve the desired results.
Use good techniques for drawing circuits and wiring diagrams, breadboarding circuits, and trouble-shooting circuits.
Use simulation tools to design circuits and analyze performance.
Work cooperatively with others in the lab to maximize results.

between the PC and the test and measurement equipment.

Savannah State University successfully used the AD2 for a two-semester sequence of remote laboratory courses for freshman [21]. Each semester course contained four basic labs that used only resistors, inductors and capacitors (no op-amps or diodes). The Savannah State study did not report student success rates or self-efficacy data. Rose-Hulman Institute of Technology has an online course that relies on the myDAC and features eight labs and two lab exams [22]. Their online labs are more advanced than the Savannah State labs, but the labs still do not address more advanced topics like active and passive filter design. The Rose-Hullman study did compare results from their online course over two summers to the results from one onsite course. Their results showed that quantitative data improved from the first online summer course to the second online offering. In fact, the second online summer data were comparable to the onsite data. However, the study did not look at self-efficacy or students' attitudes towards the course (beyond the difficulties experienced in the course). Self-efficacy is an extremely important measure as it is a direct predictor of academic satisfaction and persistence [23–25]. Furthermore, the online student success rate was extremely low, with only 35% of the students getting a passing grade (A, B, or C). Rice University has an electrical engineering lab that utilizes the myDAC and operates as a MOOC [26].

This paper significantly expands on previous work [27] as we continued our efforts at the University of Maryland to transition our traditional introductory circuits course into an online course, with the goals of achieving comparable levels for the online and onsite students with respect to:

(1) Mastery of student learning objectives.
(2) Level of satisfaction with the lab experience.
(3) Positive feelings of self-efficacy.

Our surveys and focus group questions were designed to measure our relative level of success and to understand what obstacles the online students encountered that might detract from an experience comparable to the onsite course.

The study of our new online introductory circuits course spanned four offerings from the summer 2020 semester through the summer 2021 semester and involved a total of 111 students. Spring of 2021 had the greatest number of students at 46 and summer of 2020 had the least number of students at 13. The summer classes were 100% online, but the fall and spring semester had a mix of onsite and online lab sections. Lectures for all four semesters were online for everyone. Lectures were synchronous and interactive, but recorded lectures were also available for students. A total of 34 students took the onsite version of the lab leaving 77 students in the online lab sections. There was one teaching assistant to help with each lab section, whether online or onsite. Onsite the lab sections were limited to eight students and online sections were limited to 12 students. One instructor taught the course all four times. A second instructor also taught the course in the Spring 2021 semester. In that semester, the course sequencing and laboratory requirements were highly coordinated (almost all labs were identical).

In the following sections, we describe details of the characteristics of the traditional onsite course and then the changes required for the online version of the course. Afterward, we detail our methodology for data collection and present the results of the study. Finally, we discuss our findings and summarize the conclusions drawn from our study.

1.1 The Onsite Course Paradigm

About 30 years ago, the University of Maryland compressed its two-semester introductory circuits sequence to a single semester by eliminating twoport network theory and magnetic circuits and by reorganizing the remaining material. The main difference to the order found in most classic circuit theory textbooks, e.g., [28–30], is to discuss sinusoidal steady-state analysis before transient analysis, allowing several concepts to be introduced just once with impedance and admittance, rather than once for just resistors and then a second time later in the course. It also allows for an additional method for solving transient problems via transfer functions. Initially, there was no active-learning component. About 25 years ago, a sophomore-level laboratory for both digital and analog circuits was introduced, which could be taken simultaneously with the lecture class (but not required). Ten years ago, the analog portion of the lab class was expanded and merged into a four-credit class with the lecture class, using a ''just-in-time'' coordination between lecture and lab [31].

The onsite introductory course in its present form covers all thirteen SLOs listed in the introduction. There are two 75-minute lectures per week with up to 60–72 students in the lecture. The lectures are presented synchronously by a professor. Presentations may be via prepared slides on a computer or via black/white boards. Overviews of upcoming labs are generally given in the lectures.

There are normally twelve labs in the course. There is no lab the first week of classes and the final week is reserved for make-up sessions. Each lab section meets once a week for 2 hours and 50 minutes. There are up to twelve students in each lab section. Each lab section is run by an undergraduate teaching fellow (UTF) who is trained and supervised by the course instructor. Students generally work in pairs but never in groups of three or more. Lab partners are generally rotated each week.

Except for the first three labs, each lab requires that a pre-lab be completed before going to the lab. The prelab usually includes three parts. Students must: (1) design circuits to meet the required specifications, (2) simulate those circuits to validate the designs, and (3) generate the drawings needed to construct and test the circuits. Pre-labs are done individually by students. During the lab time, students follow the lab instructions to construct and test the circuits, using the T&M equipment to obtain the needed data. Post lab reports are done in groups of two and are generally due one week after the lab was performed and detail the experimental procedure, experimental data, and answer several post-lab questions about their results. Pre-labs accounted for 30% of the grade and post-labs accounted for 60% of the grade. The final 10% was a ''class participation grade'' to ensure that all students were active participants in each lab.

This study was performed entirely during the COVID epidemic restrictions, and so onsite lab procedures were modified due to safety concerns. Onsite sections only had 8 students maximum, and the lab procedures were performed individually. However, the lab reports were still written in teams of two.

The class has no separate discussion section. The labs are designed to be done by most of the students in two hours. The remaining time is to be used for group discussions regarding both lab and lecture questions, though students who have not yet completed the lab can keep working on it. Onsite students enjoy a large selection of component values, leading to many options for design choices. However, the components are accessible to all and reusable, leading to the possibility that damaged components can be found in the supply bins.

The lab titles are given in Table 2. The first three labs serve as an introduction to the active-learning part of the course and require only reading and basic calculations for the pre-lab. The first lab introduces students to the test and measurement equipment that they will rely on all semester. Equipment includes a four-channel digital oscilloscope, a two-channel arbitrary function generator, multiple power supplies, a digital multimeter, and an LC meter. The students follow a detailed list of instructions, though they are free to explore on their own at several points in the lab. The second lab introduces students to the breadboard and building and testing simple circuits with a goal of being able to discern the inductance or capacitance of a component. The third lab introduces students to computer simulations, again by having the students follow a detailed set of instructions.

Table 2. The main topics for the onsite labs

Lab #	Lab Content	Lab #	Lab Content
1	Introduction to T&M equipment	7	Multiple input Op-Amp Circuits
2	Basic terminal relationships	8	Active and passive 4-bit D/A converters
3	Circuit simulation (PSpice)	9	Passive filter design and testing
4	Power factor measurements	10	Active filter design and testing
5	Reverse engineering - What's in the box?	11	1st and 2nd order transient circuits
6	Single input Op-Amp circuits	12	Diode circuits and AC-to-DC converters

For the remaining nine labs, the instructions are much more general, and students are expected to develop their own procedures. Lab 4 looks at sinusoidal steady-state RL and RC circuits to determine the power factor of a circuit. Lab 5 requires teams to test two of eight circuits enclosed in boxes. The circuits are either RL or RC circuits connected either in parallel or in series. The students must determine the configuration and the component values.

Lab 6 involves the design, construction, and frequency characterization of inverting and non-inverting op-amp circuits, as well as integrating and differentiating circuits. Lab 7 requires the design of a subtraction circuit and an inverting summing amplifier. Also in Lab 7, students use an LED to generate a small current and a diode as a temperature sensor, with op-amps to enhance the output. Lab 8 explores and compares passive and active 3-bit D/A converters.

Lab 9 focusses on the design and characterization of low-pass and high-pass passive filters while Lab 10 explores low-pass and high-pass active filters. First and second-order transient circuits are designed, built, and tested in Lab 11. Finally, full and half-wave, filtered and unfiltered rectifier circuits are examined in Lab 12. A Zener diode is used in the final stage to build a crude AC-to-DC converter.

1.2 The Online Course Paradigm

The content of the online course is quite similar to the onsite course. However, the two delivery methods are quite different at times. The student learning objectives that are given in Table 1 are identical for both versions of the class. The online lecture content is identical to the onsite version; however, the topics are introduced via a PowerPoint presentation. A complete set of recorded lectures was also available to students via the Electronic Learning Management System (ELMS). The presentations have worked-out examples, but during the main lecture, online students are given additional problems to work on in groups via ZOOM/Google. Since all students attended an online lecture, from now on, "online student" refers to a student who took the lab online and "onsite student" refers to one whose synchronous lab was on campus.

Each lab section was assigned their own UTF. The "UTF" for the summer 2020 offering was the course instructor, but all other sections did have an undergraduate student in each UTF position.

The department loaned each online student an ADALM2000 or an AD2. In summer and fall of 2020, online students used the Analog Discovery AD2 (or AD1) [18] but in spring and summer of 2021, online students used the Analog Devices ADALM2000 [19]. The change was due exclusively due to the unavailability of the AD2 hardware when the class size increased. While the software and hardware were different, for the purposes of the lab, the two devices were essentially interchangeable. Students were encouraged, but not required, to buy a multimeter that could also measure capacitance.

Students also received a packet that contained all the hardware they would need to do the labs. Each semester, a few additional components were added to the kit based on student feedback. The final packet included a dozen 1/4W resistor values from 51 Ohms to 100 k (5–10 each), about ten capacitors with sizes ranging from 1 nF to 22μF (2–4 each), six inductors with values from 0.1 mH to 4.7 mH (2 each), LEDs (6), 1N4007 diodes (6), a zener diode (1N746), and TLV271IP op-amps (6 each).

During the first summer session, students worked on the labs alone and asynchronously, although online office hours were used to troubleshoot labs. After the first summer session, due to student feedback, online students (1) were assigned a partner for the post-lab writeup and (2) had the opportunity to perform the labs synchronously with the UTF and the other students in the section via ZOOM. The synchronous session lasted for two hours and 50 minutes – the same amount of time for the onsite lab – however, students were not required to attend the synchronous lab nor were they required to complete the lab in under three hours. During the synchronous section, each student would be in front of their video camera with their individual hardware and build and test their labs independently. However, when they ran into some stumbling block, they could ask for help from the UTF or other students to debug their circuits. UTFs could often successfully troubleshoot circuit problems either by seeing the circuit held up to the webcam or by an email with photo attachments of the circuit in question. Also, each lab had one or two videos on ELMS that would demonstrate the basic operation of that lab. Students would forfeit their 10% participation grade if they refused to work with their assigned partner on the lab.

Ten of the twelve labs were virtually identical between the onsite and online versions in terms of complexity, content, and student learning objectives. However, some minor adjustments were made to allow for the AD2/ADALM2000s capabilities (and limitations) and for the reduction in the choice of components. An example of an advantage of the online T&M equipment is that they could perform frequency sweeps, whereas the onsite students had to study frequency characteristics manually. The online devices also had internal counters that facilitated results for the D/A lab. An example of the impact of the reduction of components is that the corner frequencies for the filter labs were carefully chosen to ensure that the circuits could be realized.

The "What's in the box" lab was eliminated (Lab 5 in Table 2). While we certainly could have added a "mystery box" to each kit, we were looking for an approach that was scalable to larger classes. Lab 1 was simply rewritten so that the student would explore the capabilities of the AD2 or ADALM2000, rather than the test and measurement equipment in the onsite lab. Functionally, they were essentially the same. A lab zero was introduced in which the students would simply download and run the software for the AD2 (Waveforms) of the ADALM2000 (Scopy), so essentially there were 11 online labs.

2. Methodology

Our three research questions revolved around how to design and execute the online laboratory so that there would be no difference in the online and onsite students' (1) mastery of the SLOs, (2) satisfaction with the lab experience, and (3) self-efficacy regarding their laboratory knowledge, skills and abilities (KSAs). There were two types of assessments used to compare the two lab modalities. The first was the normal formative assessment, in which the pre- and post-lab reports were graded. The second assessment involved student surveys at the beginning and at the end of the semester. In all surveys, students were asked to rate each question from strongly disagree (–2) to strongly agree (+2), so a score of zero represents a neutral response. Small virtual focus groups were also held at the end of the course for the first three offerings, to which both onsite and online students were invited.

2.1 The Pre-Lab Survey

Before the labs began, in all semesters except for the first, both online and onsite students were asked about their preferences for the lab location and about their expected outcomes if they were to take the labs online or onsite. They were also asked if they would want to work on the post-lab reports with a partner. Students were able to self-select either online or onsite labs. Most pre-lab survey data was not separated by the lab type the students selected.

The results of the survey regarding location preference are shown in Table 3. The response mean (M) and the standard deviation (SD) are shown in the table. The students weakly preferred to have the lab in person over the online option. However, cost was an important factor. When asked if the students still wanted their preference even of it cost $250 more than the alternative, students preferred to switch to the other delivery method, irrespective of their initial choice. Students did demonstrate concern for the COVID-19 situation.

Table 3. Location preference for all students

Survey Prompt	M	SD
I would prefer to perform the laboratory component in the lab room.	0.41	1.17
I would prefer to perform the laboratory component online at home.	0.12	1.15
I would prefer to perform the laboratory component in the lab room on campus even if it cost $250 more than performing it online.	–0.98	1.35
I would prefer to perform the laboratory component online at home even if it cost $250 more than performing it on campus.	–1.15	1.18
If I were performing the lab on campus, but then the risk for COVID-19 increased significantly, I would want to switch to online.	0.86	1.13

Table 4. Quality expectations for the online lab

If I took the lab online. . .	M	SD
I think it would be harder to get help if I had problems or questions as compared to on campus.	0.86	1.13
I think it would be impossible to get timely help if I had problems or questions.	0.22	1.19
I feel that I would have a better experience than in the room on campus.	–0.67	0.95
I think it would learn just as much as if I took the class at the lab on campus.	0.22	1.19
I would do the lab during the regular lab time because there would be a teaching assistant online to help me with any questions.	0.98	1.11
I would do the lab whenever it was convenient for me, even though there would be no one online to help me with any questions.	0.32	1.08

The students' pre-lab responses to their expectations for the online version of the lab are given in Table 4. Overall, they mostly had negative expectations for the online lab. The students believed that it would be harder to get help in the online sections, but not necessarily impossible to get timely help. They did not believe that the online lab experience would be better than the onsite lab experience. When asked if they felt students would learn as much in the online lab as in the onsite lab, the average response is just slightly positive. Students were asked if they would plan to do the lab synchronously with the UTF and other class members or if they would plan on doing the lab alone when it was most convenient for them. On average, they agreed that they would do the lab during the scheduled lab period and fewer preferred to attempt

Table 5. Partner preference versus partner experience

Survey Prompt	Onsite		Online	
	M	**SD**	**M**	**SD**
I would prefer to have a partner who would do the lab his/herself but would work together with me on the lab report.	*0.49*	*1.41*	*0.92*	*1.33*
Working with a partner on the lab report was very useful	1.14	1.12	0.81	1.30
Working with a partner on the lab report was very frustrating at times	–0.36	1.17	–0.02	1.23

the lab when there was no immediate help available. In reality, most students declined to attend the synchronous sessions in favor of attempting the labs at their own convenience. Some students would opt to work on the labs via ZOOM with just their lab partner for the week. Therefore, when most students reached an impasse in their lab work, they would send an email to the instructor or UTF or attend the next available office hour.

2.2 The Post-Lab Survey

The results of the post-lab surveys for the students from all four semesters are given in Tables 5–7. The post-lab data is separated by the type of lab the students were enrolled in. Table 5 addresses the use of partners for the post-lab reports. The first entry in the table is from the Pre-lab surveys to contrast expectations with experiences. If the students were onsite, there was mediocre desire to work with someone else on the lab report, but if online, the average response indicated an agreement to have post lab partners. At the end of the semester, both onsite and online lab students agreed that it was very useful to work with a partner on the post-lab report, even though they took their data separately. The onsite students found the partner work somewhat more useful than the online students did. Online students were virtually neutral toward the idea that it was very frustrating to work with partners at times, while onsite students somewhat disagreed with that statement.

Student impressions of the laboratory component are summarized in Table 6. The first three prompts address the students' impression of the quality of the lab instructors and course materials, while the remaining questions address their evaluation of the lab operation. In general, the onsite labs were scored significantly higher than the online labs.

For the question as to whether the UTF gave a lot of timely help, the onsite score was almost a full point higher than the online score. No doubt the synchronous nature of the onsite labs helps to explain the difference, but the online students had the opportunity for synchronous interactions and most students simply chose not to take advantage of the opportunity. The online student response to this prompt varied considerably from one semester to the next, as shown in Fig. 1. Summer 2020, when the instructor served as the UTF, had the most positive response, while the largest class, spring 2021, had the most negative response.

On the question of instructional materials, the onsite students rated their adequacy 0.78 higher – three-quarters of a point. The two groups had access to identical instructional materials, and the lab videos were relevant only to the online students; there were no videos about the onsite labs. The breakdown to the online response to this prompt is given in Fig. 2. There seems to be some correlation between the two prompts in Figs. 1 and 2: the summer of 2020 had the most positive response for both prompts and Spring 2021 received the greatest negative response for both prompts. Each semester, the number of instructional materials on ELMS for online students only increased, culminat-

Table 6. Students' impression of the laboratory component

Survey prompt	Onsite		Online	
	M	**SD**	**M**	**SD**
The lab assistant (UTF) gave me a lot of timely help with the labs	*1.23*	*1.05*	*0.28*	*1.34*
The instructional materials provided were adequate to perform the labs.	*0.63*	*1.11*	*–0.15*	*1.09*
The physical resources (equipment, components) were adequate to perform the labs.	*0.50*	*1.18*	*–0.06*	*1.34*
I enjoyed the laboratory component of the class.	0.80	1.11	–0.28	1.16
I feel I learned as much as the students who took the other type of lab session.	1.07	1.00	–0.22	1.30
I felt frustrated now and then while trying to do the labs	1.10	0.98	1.46	0.68
I felt frustrated way too often while trying to do the labs.	0.10	1.33	0.62	1.07
There were times doing labs when I felt lost.	1.03	1.11	1.28	0.87
There were times I felt that the labs were too easy.	–0.97	1.08	–1.19	0.81

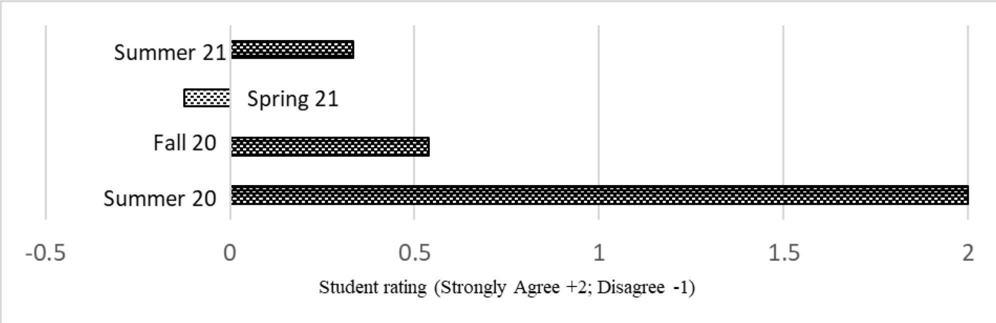

Fig. 1. The online students' response to "The lab assistant (UTF) gave me a lot of timely help with the labs" broken down by semester.

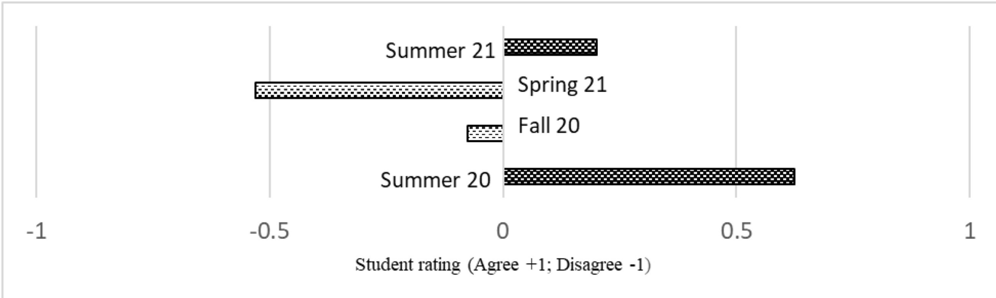

Fig. 2. The online students' response to "The instructional materials provided were adequate to perform the labs" broken down by semester.

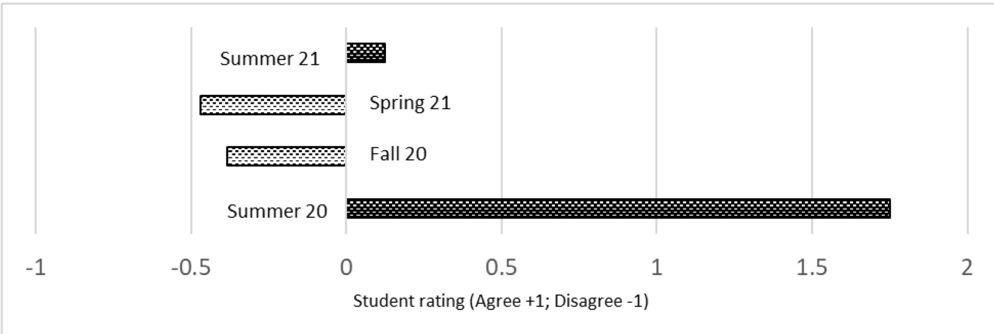

Fig. 3. The online students' response to "The physical resources (equipment, components) were adequate to perform the labs." broken down by semester.

ing in the complete set of online instructional videos in Summer 2021. Hence, the negative responses could be related to the opinions about the course staff. Student opinion as to the adequacy of the hardware for the online lab is broken down by semester in Fig. 3. As with the instructional materials, the amount of hardware supplied to the online students only increased with each subsequent semester and so there must be another root cause for the dissatisfaction with the available hardware.

The final six prompts in Table 6 involved the students' relative satisfaction with the lab. For all six prompts, the onsite students were more satisfied than the online students. The onsite students rated their enjoyment of the lab over a full point higher than the online students did. The onsite students also agreed that they learned as much in the lab as the online students, whereas the online students slightly disagreed with the notion that they learned as much as the onsite students. Again, the results for the online students varied considerably from one semester to the next. Fig. 4. demonstrates the variation in enjoyment of the lab for the online students. Summer 2020 students had a very positive experience while Spring 2021 students had a very negative experience, which is very much in line with the responses to the first three prompts.

The differences in online and onsite responses for the final four prompts were less significant, but the onsite students felt somewhat less frustrated and

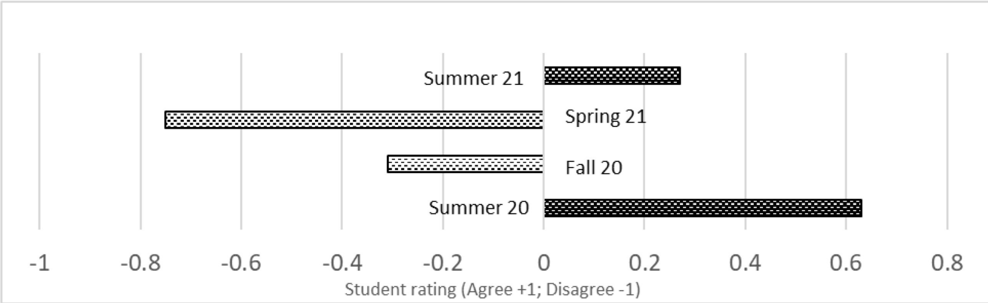

Fig. 4. The online students' response to "I enjoyed the laboratory component of the class" broken down by semester.

somewhat less lost on occasion. Both groups disagreed with the statement that they felt the labs were too easy at times.

The students' views on self-efficacy are shown in Table 7. Almost all students felt somewhat positive about their self-efficacy. The one exception involves the ability to debug circuits, for which onsite students were neutral and online students were slightly negative. Regarding the five questions about the students' knowledge, skills, and abilities (KSA), the average score for onsite students was 0.33 while the online students average was 0.25. The summer 2020 online student average response (not shown in the table) was the highest of all at 0.63! Online students felt better about simulating circuits and onsite students felt better about the other four KSAs, but the standard deviations greatly exceeded the differences in the averages for all five prompts.

Despite the similar KSA scores, there was a difference as to the views the students hold regarding how useful the lab skills will be in future lab courses. The onsite students were very optimistic about how useful their KSAs would be, while the online students were only weakly optimistic.

2.3 Student Summative Assessment

Student assessment was performed both by the instructor (quizzes, midterms and final exams) and by the UTFs (pre- and post-lab reports and homework). Little effort was made to improve interrater reliability between UTFs. Sixteen of the students were female (14.4%), five students were Hispanic (4.5%), and 14 students were African-American (12.6%). Six of the female students were either Hispanic or African American and so there were 82 (or 74%) white or Asian male students.

The percentage of students passing the course was 88% both for the full cohort and for the underserved population. The percentage of online students passing the course was 92%. Thus, most students successfully completed the course, students from underserved populations did as well on average as the other students in the class, and the students who took the online lab sections appeared to do at least as well as students who enrolled in the onsite sections.

Seven months after the end of the final offering of the course (summer 2021), students were asked to rate how effective various aspects of our course (205) were for preparing the students for a junior-level electronics lab class (307). This follow-on lab is required only for electrical engineering students, though computer engineering students may take the course. Results from that study by students who took 307 are summarized in Table 8.

Onsite students had a slightly negative impression of the usefulness of their simulation tools in the follow-on course, but all other indicators were slightly positive or better. Online students rated their simulation skills and their analysis techniques higher, while the onsite students rated their debugging skills and test and measurement equipment

Table 7. Students' self-efficacy rating

Survey Prompt	Onsite		Online	
	MS	**SD**	**M**	**SD**
I feel that I know how to use the test and measurement equipment competently.	0.73	0.93	0.51	1.00
I am good at designing circuits.	0.17	1.00	0.04	0.99
I am good at simulating circuits.	0.20	1.08	0.54	1.05
I am good at building and testing circuits.	0.50	0.99	0.37	1.03
I am good at debugging circuits.	0.03	1.02	–0.21	1.11
I feel the knowledge, skills, and abilities that I learned in the lab will help me in future lab classes.	1.20	0.54	0.66	1.12

Table 8. The utility of 205 lab knowledge, skills, and abilities for the 307 lab class

Survey Prompt	Onsite	Online
The debugging skills I learned in 205 helped me to be successful in 307.	0.67	0.29
The circuit simulation techniques I learned in 205 helped me to be successful in 307.	–0.17	0.29
The circuit analysis techniques I learned in 205 helped me to be successful in 307.	0.50	1.00
The test and measurement equipment skills in 205 helped me be successful in 307.	0.50	0.29
Overall, I feel that my 205 lab experience has helped me be successful in 307.	0.83	0.43

knowledge higher. The online responses never trailed the onsite responses by more than 0.4 whereas the onsite responses trailed online responses by about 0.5. The standard deviations are not listed in the table but were between 0.8 and 1.4. The onsite students did rate their class to be overall more helpful in 307, though the online students also had a positive rating and the difference in averages was much less than the standard deviation.

2.4 Focus Group Results

A total of eight students participated in three separate focus groups: one student from the 2020 summer class, five students from the fall semester, and two students from the spring semester. Five of the students took the labs online and three onsite. Of the eight students, two were female, one was Hispanic, and one was African American. All of the students who participated in the focus groups had overall positive feelings about the lab component of the course, but they did have a number of useful comments and suggestions.

Onsite students repeatedly brought up two issues in their comments. First, they noted that there were often damaged op-amps and bad wires. Onsite students share common hardware bins and return borrowed components at the end of each lab. Even though students are told to throw away any electronic components or wires they believe to be damaged, faulty op-amps are often found in the common bins. On the positive side, the onsite students' favorite lab feature was the immediate access to the UTF to consult them about debugging techniques, clarifying lab procedures, and answering general questions about course material.

Online students appreciated receiving new components and there were no complaints about bad wires or damaged op-amps. However, many students voiced their desire to have a greater selection of components, especially capacitors, inductors, and wires, or that parts were missing, or that the hardware was too disorganized (all components came in a single bin). These comments helped us to increase the number of components each semester until we arrived at the final list that generally seemed to be adequate.

The one student from summer 2020 was an African American male from a different college taking the course as a special summer student. He really appreciated the video demonstrations of the labs, saying that it gave him that "in-person feeling" and stating that he thought that watching the videos should be mandatory for all students. A student from fall agreed that the videos were "more than helpful", but that the quality of some could be improved and that there should be videos for all labs. For the final two course offerings some videos were remade and at least one video for each lab was uploaded to the LMS system. The Hispanic student from the spring semester agreed that the videos were "extremely helpful."

The summer student suggested that the labs be done synchronously and that students should have partners for the post-lab results. Both suggestions were implemented, and while working with a lab partner was required, attending the synchronous lab times was optional. According to the focus group participants, some online students appreciated the fact that they could perform the labs at their convenience, while others stated that they wanted to work simultaneously online with their partner. As mentioned before, despite the expression of the desire to work together, few students attended synchronous online lab times when they were made available.

Both online and onsite students appreciated working with partners, even though most students just interacted with their partners for the final lab report. Since lab partners were rotated, the quality of the interaction varied from week to week. One focus group participant noted that the labs with the most interactive partner were his favorites and the ones where contacting the partner was difficult were among the least. Another participant agreed that the quality of the interaction varied greatly and that negative interactions "happened more times" than he would have liked.

Most participants would have preferred to have more detailed instructions for labs 4–12 and some agreed that they would have liked to verify their results prior to turning in their lab report. One participant suggested that in addition to the videos, there should be photos of some of the more complicated lab circuits on the LMS.

Finally, one focus group participant suggested that we use a "more friendly" simulation package like CircuitLab [32]. While we do require students to perform the third lab with PSpice, students are told that they may use any circuit simulation tool they like. We specifically point them to two free applications: CircuitLab and MultiSim [33]. We simply let them know that if they have problems performing the simulations, the UTFs are only guaranteed to be able to help them with PSpice.

3. Discussion

Our study suffered from uneven populations of online and onsite students and from the fact that students self-selected and may not have received their first choice for lab format, given the realities of full sections and restrictions on the size of the onsite lab sections. We could not take additional data as all labs reverted to onsite after the summer of 2021. Also, one instructor taught over 80% over the students. We did not report data on the assessment of lab reports as there was little effort to ensure interrater reliability, yet the quality of lab reports overall seemed comparable for the two groups of students. Finally, the online lab hardware and resources were modified each semester and so no steady state was reached.

From all the data gathered, including the survey results, focus groups, and student success rates, it appears that students who took the online version of the lab mastered the course KSAs sufficiently to achieve positive feelings of self-efficacy and to be prepared for follow-on courses. Though the sample size was small, success rates were similar regardless of a student's gender, race, or ethnicity. While many large standard deviations in the survey results indicate variations in the student experience, it appears that the technical content of the online lab and the hardware used were adequate. However, the delivery of the lab instructional material and the support given to the students needs to be improved. While the instructional videos were significantly enhanced after the first offering of the course, higher quality and more detailed videos would have been appreciated by the students. Additional training of the undergraduate teaching assistants should also help, given that the highest overall satisfaction ratings for all students – online and onsite students – was during the online summer session when the professor served as the teaching assistant. Either providing some incentive so that, or requiring that, online students attend synchronous lab sessions may help improve the online satisfaction rating.

While the COVID-19 restrictions were the driving force for the development of the online version of the class, there are a number of possible scenarios, besides the resurgence of a contagious illness, for which the online version of the lab course could be beneficial. In our course, there is at most one week in the semester slated for make-up labs and making up labs outside of the scheduled lab times can be problematic. When a student misses one or more labs, we ask the student to check out a kit that contains the ADALM2000, a breadboard, and all the necessary components so that they can complete the lab(s) at home. The summer session could also be a convenient time for the online version of the course, as many students who would like to take the course can't take it due to their work / internship obligations. Finally, many universities have long-distance learning arrangements with institutions (or MOOCs) who may not have the needed test and measurement equipment, so the online lab offers a low-cost solution.

4. Conclusions

A full online version of a traditional introductory circuits course has been developed and taught multiple times. Students' attitudes, beliefs, and performances after taking the online course have been compared to the those of students whose lab sections were onsite. The results of this study show that the online modality does successfully train students, as online students reported their self-efficacy nearly on par with those of the onsite students, and the online students had equal academic performance compared to their onsite counterparts. However, the satisfaction level of the online lab students lags the satisfaction level of the onsite lab students, and a critical factor to overall course satisfaction appears to be the performance of the lab assistants.

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A copy of all the course material can be found at: https://terpconnect.umd.edu/~lawson/enee205.html.

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