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Development, Implementation, and Evaluation of an Asynchronous Online Electric Circuits Laboratory

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Abstract – We detail the development, implementation, and evaluation of a completely asynchronous online version of an electric circuits laboratory. We compare the attitudes of the online students to the attitudes of those who took the lab in person (on-site) at the university. Online students were sent a kit that included a component box with the needed hardware and electronic components. They also received a USB-based test and measurement (T&M) device (which integrates two oscilloscope channels, two signal generators, and two power supplies) and they had to download the software for the computer interface before working with the T&M device. On-site students performed the labs in a synchronous setting with an undergraduate lab assistant and with more traditional T&M equipment. The online students also had access to a lab assistant, though the help was asynchronous. Student surveys and focus groups were used to evaluate the student's level of satisfaction towards the circuits laboratory as well as their self-efficacy. While the on-site students were generally more satisfied with their lab experience, the two groups emerged from the experience with nearly equal positive feelings of self-efficacy. The evaluation revealed both weaknesses and strengths of the online version and those revelations have informed modifications to the online process for future semesters.

Introduction – The demand for online classes has been rising rapidly in the past two decades and has further accelerated recently due to COVID-19. In that timeframe, there have been many engineering lecture courses converted to online formats with considerable success [1]. Online lab courses for electrical engineering students have also been tried for several decades. The first online labs typically have involved performing computer simulations of the electronic circuits, though some have utilized remote control of the test and measurement equipment [2]. In more recent years, there have been a number of relatively low-cost test and measurement devices that connect to a computer via a USB cable and run software that allows the student to take measurements and display them on an "oscilloscope" on the computer monitor. These devices also have built-in power supplies and waveform generators and some have a digital multimeter. They typically have two analog channels and 16 digital inputs [3-5]. While prices vary and there are often student discounts, the NI myDAC [3] and the NI Diligent Analog Discovery 2 [4] are both around $400 and the Analog Devices ADALM2000 [5,10] is around $250.

The Analog Discovery 2 (AD2) has been successfully used for a remote laboratory at Savannah State University [6]. The AD2 was used for a two-semester sequence of courses for freshman. There were four fairly basic labs for each semester that used only resistors, inductors and capacitors (no semiconductor devices) and student success rates and self-efficacy were not reported. The use of myDACs for an online lab have also been reported [7,8]. At Rose-Hulman Institute of Technology, the online course featured eight labs and two lab exams [7]. Their labs were more advanced than the Savannah State labs but still did not include more advanced topics like active and passive filter design. They compared their fully online courses over two summers to the results from one fully on-site course. Their results showed that quantitative data improved from the first to the second online offering to the point that the second online results were comparable to the on-site data. However, they did not look at self-efficacy and students' attitudes towards the course (beyond the difficulties experienced in the course). 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 runs an electrical engineering lab as a MOOC [8].

The investigation of our online sophomore electrical engineering course at the University of Maryland with a laboratory component spanned the summer and fall semesters of 2020 and involved a total of 44 students. Thirteen students took the online course during an 8-week summer session. The 31 students who took the fall offering class self-selected their lab sections and were nearly evenly split between the on-site version (15 students) and the online version (16 students). The same instructor taught all three groups of students. The lectures were online and synchronous for all students. The “lab assistant” for the summer was the course instructor. For the fall, there were four undergraduate lab assistants – two for online sections and two for on-site sections. All students were asked to perform the same laboratories. There were two layers of assessment. The first was the usual course assessment, in which the post-lab reports were graded. The second assessment involved pre- and post-lab surveys and focus groups for both onsite and online students.

In order to perform the online labs, electronics kits, which contained a Diligent Analog Discovery 2 Device (AD2) [1], or equivalent, as well as a breadboard, wires, operational amplifiers, diodes, resistors, capacitors, and inductors, were sent to each student. Students were not given a multimeter or an LC meter. Videos were made to demonstrate the set-up of the AD2 software and hardware, as well as the operation of the AD2 and the assembly and testing of initial labs. The videos were available via the learning management system (LMS) for the course. The online labs were adjusted from the onsite versions of labs from previous semesters to allow for the AD2s capabilities (and limitations) and for the reduction in the choice of components, but were equivalent in terms of complexity, content, and student learning objectives. While the labs were to be performed asynchronously, students could consult virtually with the instructors, and could show their circuits and the software results and receive help with the debugging and running of their circuits.

On-site students utilized a typical four-channel digital oscilloscope (Agilent DSO-X-2014A) and had access to a two-channel function generator (Agilent 33510B), digital and analog power supplies, a digital multimeter (Fluke 8808A), and an LC meter (Agilent/Keysight U1732C). On-site students also had access to a much larger inventory of components. These components were shared by all the on-site students and were typically re-used week after week.

There were three parts to most every lab irrespective of whether the student was online or on-site. Before the lab was begun, students needed to complete a pre-lab, which started with the fourth lab had three components: (1) circuits needed to be designed to meet the required specifications, (2) the designed circuits needed to be simulated to verify the expected outcomes, and (3) adequate circuit drawings needed to be generated. The first three labs of the semester had reduced requirements for the pre-labs. Students were required to complete the pre-labs individually. The second phase was to perform the labs, *i.e.* follow the general instructions to build and debug the circuits and to use the T&M equipment to gather the required data. This phase was also done individually for both online and on-site students (the latter due to COVID-

19 restrictions). The final phase was to write up a lab report detailing the experimental process and results and answering some additional questions about the labs. For the final part, students were assigned a partner to write the report together and to turn in only one report per group.

Detailed description of the labs – The titles for the eleven labs required for the course are given in Table I. The first three labs served as the introduction to the laboratory and consequently gave the students detailed, step-by step instructions to follow. The objective of the first lab was for students to get acquainted with the oscilloscope (or AD2) and did not use any hardware. The second lab objective was to observe the consequences of terminal relations for inductors, capacitors and resistors. For inductors and capacitors, a series resistance was added to obtain the current through the component. The third lab was a computer lab only with the objective that students became familiar with PSpice [9].

Table I. The key concepts of the online labs

Lab #	Lab Content
1	Introduction to T&M equipment
2	Basic Terminal Relationships
3	Circuit Simulation
4	Power Factor Measurements
5	Single Input Op-Amp Circuits
6	Multiple Input Op-Amp Circuits
7	Active and Passive D/A converters
8	Passive Filters
9	Active Filters
10	Transient Circuits
11	Diode Circuits

Table II. Component list for the online lab kits

Resistor value (Ω)	Quantity	Capacitor value (µF)	Quantity
51	9	0.1	2
100	9	1.0	2
200	9	10	1
390	9	Diodes	Quantity
1k	9	1N4007	6
2k	9	LEDs	6
3.9k	9	Op-AMPS	Quantity
10k	9	LM741	4
Inductor value (mH)	Quantity		
4.7	2		

For the remaining eight labs, students were given more general instructions for the labs as the students were expected to know what steps were needed to design, build, and test the circuits to obtain the requested data. Four labs utilized op-amp circuits (5,6,7, and 9) and five labs utilized passive circuits (4,7,8,10, and 11). Only the 10^{th} lab on transients required students to master single-shot operation of the T&M equipment. Only the final lab used diodes in the circuits.

The components that the summer students received in the kit are listed in Table II. The inductor and capacitor selection proved to be inadequate for the students and so the number of components was increased for the fall semesters. The fall students still felt that they needed additional hardware, and so we added a few more inductors and capacitors and plan to use the component list in Table III for all future online labs. The op-amp was also changed for one that is more compatible with the lower maximum voltage capability of the AD2 power supplies.

The Pre-Lab Survey - Before the labs began in the fall, all students were asked about their preferences for the location of their labs and about the expected outcomes if they were to take the labs online or on-site. They were also asked about their preferences for partners. Students were able to self-select either online or on-site labs. The survey questions (both pre- and post-lab) were reviewed by other faculty at the University of Maryland who teach the same course.

Table III. Component list for the online lab kits					
Resistor value (Ω)	Quantity	Capacitor value (μF)	Quantity	Inductor value (mH)	Quantity
51	5	.001	4	0.1	2
100	5	.01	4	0.22	2
200	5	0.1	4	0.47	2
390	5	0.22	2	1	2
1k	10	0.47	2	2.2	2
2k	10	1.0	2	4.7	2
3.9k	10	2.2	2	10	2
10k	10	10	2	47	2
20k	10	47	2	Diodes	Quantity
50k	5	220	2	1N4007	6
100k	5	Op-AMPS	Quantity	1N746	2
200k	5	TLV271IP	4	LEDs	6

The results of the survey regarding location preference are given in Table IV. The students were asked to rate each question from strongly disagree (-2) to strongly agree (+2), so a score of zero represents a neutral response. The response mean and the standard deviation are shown in the table. The students weakly preferred to have the lab in person in the lab room (even though the course registration was evenly split between online and on-site). However, when asked if the students still wanted their preference even of it cost $250 more than the alternative, many students preferred to switch to the other delivery method. This result led us to find a way to provide the hardware to the online students at no cost to them. On-site students did want to switch to online delivery if the COVID-19 situation worsened.

Table IV. Location preference for all students in Fall 2020 class	mean	std dev
I would prefer to perform the laboratory component in the lab room.	0.545	1.34
I would prefer to perform the laboratory component online at home.	-0.476	1.26
I would prefer to perform the laboratory component in the lab room on campus even if it cost $250 more than performing it online.	-0.667	1.43
I would prefer to perform the laboratory component online at home even if it cost $250 more than performing it on campus.	-1.238	1.13
If I were performing the lab on campus, but then the risk for COVID-19 increased significantly, I would want to switch to online.	0.714	1.63

The students' pre-lab responses to their expectations for the online version of the lab are given in Table V. Again, students chose from strongly disagree (-2) to strongly agree (+2). The students unequivocally felt that it would be harder to get help in the online sections and they definitely felt that the in-person experience would be better than the online experience. The students weakly felt that they would not learn as much with the online lab. Students felt that if they had to do the lab online, they would prefer to do it synchronously so that a lab assistant would be present while they attempted the lab.

Table V. Quality expectations for online lab for all students in Fall 2020 class	mean	std dev
If I took the lab online, I think it would be harder to get help if I had problems or questions as compared to on campus.	1.190	0.54
If I took the lab online, I think it would be impossible to get timely help if I had problems or questions.	0.000	1.11
If I took the lab online, I think it would learn just as much as if I took the class at the lab on campus.	-0.571	0.85
If I took the lab online, I would do the lab during the regular lab time, because there would be a teaching assistant online to help me with any questions.	0.714	0.88
If I took the lab online, 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.	-0.143	0.83
If I took the lab class online, I feel that I would have a better experience than in the room on campus.	-1.286	0.88
Table VI. Partner preference for all students in Fall 2020 class	mean	std dev
If I took the lab online, I would prefer to have a "partner" who would do the lab in his/her house, but would work together with me on the lab report.	0.810	1.18
If I took the lab on campus, I would prefer to have a "partner" who would do the lab his/herself, but would work together with me on the lab report.	0.857	0.94

Finally, students preferred to coauthor the post-lab report with a partner irrespective of whether they were in the online section or the on-site section (Table VI).

The post-lab survey – The detailed results of the post-lab surveys for all three cohorts (summer online, fall online, and fall on-site) are given in Tables VII and VII. The results are also presented graphically in Figs 1 and 2, for which the number in the figure corresponds to the number of the prompt listed in the table. Standard deviations were not given in the tables but were similar to the standard deviations from the pre-lab (typically near 1).

The impression that students had regarding how much they learned relative to the other format mirrored the pre-lab result with on-site students definitely feeling that they learned as much as the online students and online students definitely feeling that they did NOT learn as much as the on-site students. Only the fall online students felt that the physical resources were somewhat inadequate. Since the summer students actually had fewer components than the fall online students, the response difference might be related to the different perceptions of available help (see number 6 in the table). The fall online students were just barely negative on whether the instructional materials were adequate, while both the summer students and the on-site students were both quite positive about those materials.

Table VII. Survey Prompts regarding the students' impression of the laboratory component of the course		Fall Onsite	Fall Online	Summer Online
1	I feel I learned as much as the students who took the other type of lab session.	1.07	-0.31	-1.13
2	The physical resources (equipment, components) were adequate to perform the labs.	0.53	-0.38	1.75
3	The instructional materials provided were adequate to perform the labs.	0.93	-0.08	0.63
4	I felt frustrated now and then while trying to do the labs	1.07	1.38	1.38
5	I felt frustrated way too often while trying to do the labs.	-0.27	0.69	-0.25
6	The lab assistant gave me a lot of timely help with the labs	1.27	0.54	2.00
7	There were times doing labs when I felt lost.	1.07	1.23	1.00
8	There were times I felt that the labs were too easy.	-0.53	-1.46	-0.75
9	I enjoyed the laboratory component of the class.	1.20	-0.31	0.63

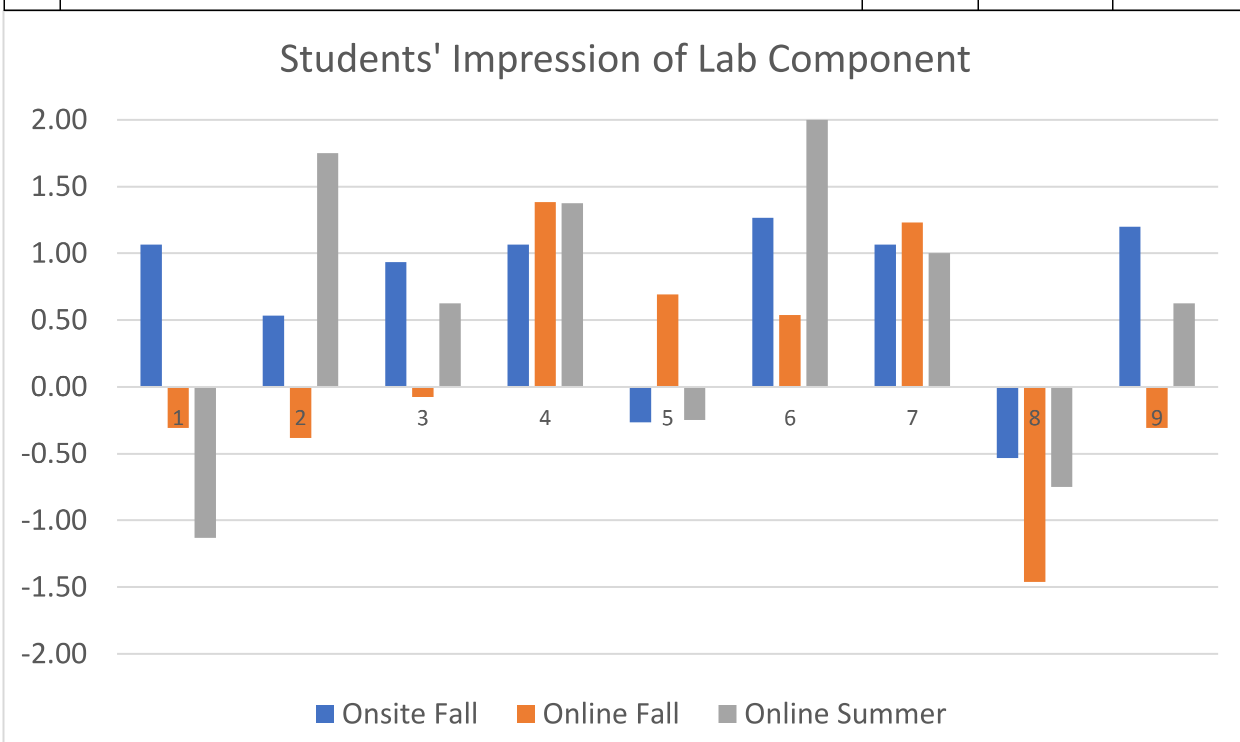

Figure 1. The students' impression of their version of the laboratory component of the class.

All students definitely felt frustrated while doing the labs now and then, but only the fall online students felt frustrated “way too often.” All of the cohorts felt that they were sometimes lost while doing the labs, and none of the cohorts felt that the labs were too easy, though the online student felt more strongly about this than the on-site students. On the subject of whether or not the students received sufficient, timely help, the summer students were unanimous in their strong agreement, while the on-site students clearly agreed that they did and the fall online students only weakly felt that they got enough timely help. The on-site students strongly enjoyed the lab and the summer students weakly enjoyed the lab, but the fall online students weakly did NOT enjoy the lab.

The students’ views on self-efficacy are shown in Table VIII and Fig. 2. The first thing to notice is that all cohorts felt generally positive about their self-efficacy. When you look at the questions about the students’ knowledge, skill, and abilities (KSA questions 1-5), the average score for on-site students was 0.45 while the fall online students average was 0.42 and the summer online student average response was the highest of all at 0.63. Online students felt better at simulating circuits and debugging circuits as compared to the on-site students. While the standard deviations are such that slight differences in these numbers may not be significant, it is significant that although the online students felt that they did not learn as much as the on-site students and some did not enjoy the laboratory component, they still feel as confident as the on-site students about their laboratory KSAs. In spite of 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 and in future jobs. The on-site students were very optimistic about how useful their KSAs would be, while the fall online students were only weakly optimistic. The summer online students’ optimism was in between the responses of the two fall cohorts.

Student summative assessment – The individual undergraduate teaching assistants graded the labs for their students only and no attempt was made to improve interrater reliability. However, the course instructor graded all of the quizzes and exams. For the fall semester, the final grade averages for the online and on-site students were within 0.6% of each other, whereas the standard deviation for the class as a whole was over 12%, indicating that the two cohorts were relatively equal in terms of their content knowledge.

Focus group results – Focus groups, led by Prof. Kouo, were performed as an additional validation of survey results. Five students participated in focus groups. One student was from the online summer class and two students each from the fall online and on-site versions of the labs. In addition, many students answered open questions on the second student survey.

Two unique themes emerged from the on-site student responses. First, students complained about faulty components, especially about operational amplifiers not working. Students return hardware to collective bins at the end of each on-site lab for use by the next group. Although students are told to discard any suspect components, evidently many faulty op-amps are returned to their bin. Op-amps are probably the easiest component to accidently damage. Second, the online students’ favorite part about the labs was the instant access to the laboratory assistant for help with trouble-shooting circuits and answering procedural questions.

Table VIII. Survey Prompts regarding the students' self-efficacy		Fall Onsite	Fall Online	Summer Online
1	I feel that I know how to use the test and measurement equipment competently.	0.93	0.54	0.88
2	I am good at designing electric circuits.	0.47	0.23	0.63
3	I am good at simulating electric circuits.	0.07	0.46	0.88
4	I am good at building and testing electric circuits.	0.73	0.54	0.63
5	I am good at debugging electric circuits.	0.07	0.31	0.13
6	I feel that the knowledge, skills, and abilities that I learned doing the labs will help me in my future lab classes.	1.40	0.54	1.13
7	I feel that the knowledge, skills, and abilities that I learned doing the labs will help me in my future profession.	1.20	0.38	0.75

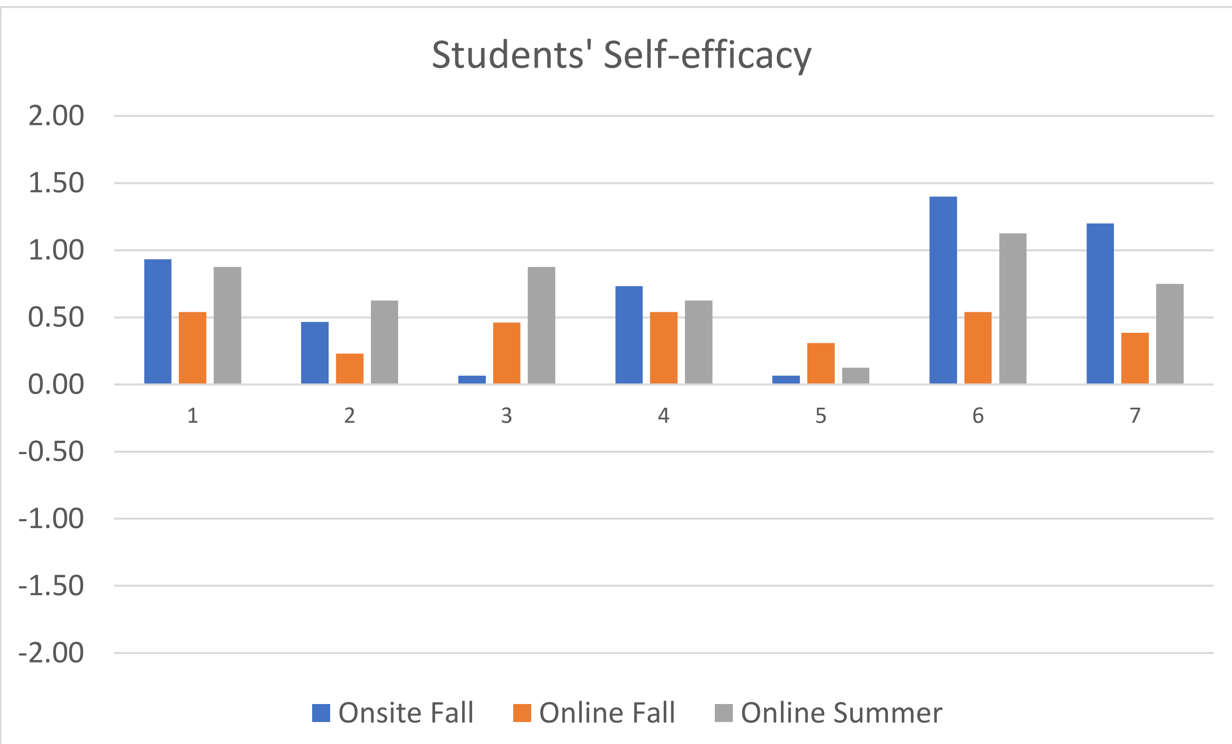

Figure 2. The students' views on self-efficacy for the lab portion of the class.

On the other hand, online students enjoyed new hardware and there were no complaints about faulty hardware. However, there were many complaints about insufficient quantities of hardware, especially capacitors, inductors, and wires. Some online students enjoyed the fact that the labs were asynchronous, while most preferred to have synchronous times where students could work together in an online meeting. Online students particularly liked the videos that were on the LMS system and complained that there were no demonstration videos for the final few labs.

Both online and on-site students appreciated working with partners, albeit only to do the write-up of the final lab report. All cohorts wanted to see more specific instructions for the later labs and most complained that they wanted to see if their results were what was expected.

Summary and conclusions – The results of this study showed that there is still much work to do to raise the satisfaction of the online lab students up to the level of the on-site lab students. There is hope that this can be achieved, as the self-efficacy beliefs of the online students rivaled those of the on-site students and because the summer lab with the more experienced lab assistant achieved considerably better ratings than the fall online students on a number of important prompts.

For the next iteration of the online lab (spring 2021), we have increased the component kit size, we have increased the number of online videos – one for each lab, focusing on demonstrating the desired outcomes for a number of the labs, and we have somewhat increased the amount of detailed instructions in the later labs (4-11). We will post on the LMS the plots of key data from the computer simulations. We are going to assign online lab partners earlier, and we are going to request that the lab partners arrange a time when they can work on their lab synchronously. We are also switching to the ADALM2000 due to cost and availability issues, though the AD2 could be used for the lab by using the Waveforms software instead of Scopy. Finally, we have expanded the number of hours we offer for optional synchronous lab time and we continue to assess student satisfaction and self-efficacy.

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