2023 Annual Conference & Exposition
Baltimore Convention Center, MD | June 25 - 28, 2023
The Harbor of Engineering Education for 130 Years
Paper ID #38743

Board 208: Achieving Active Learning through Collaborative Online Lab Experiences

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Achieving Active Learning through Collaborative Online Lab Experiences

Abstract

In engineering education, laboratory learning that is well aligned with core content knowledge is instrumental as it plays a significant role in students' knowledge construction, application, and distribution. Learning in laboratories is interactive in nature, and therefore students who learn engineering through online platforms can face many challenges with labs, which were frequently documented during the recent pandemic. To address those reported challenges, innovative online lab learning modules were developed and learning strategies were implemented in five courses in electrical engineering, Circuits I, Electronics I, Electronics II, Signals and Systems, and Microcomputers I, through which students gain solid foundation before students take on senior design projects.

Lab modules with open-ended design learning experience through using a lab-in-a-box approach were developed to allow students to solve lab problems with multiple approaches that allow problem solving independently and collaboratively. Because this innovative lab design allows problem solving at various cognitive levels, it is better suited for concept exploration and collaborative lab learning environments as opposed to the traditional lab works with a "cookbook" approach that tend to lead students to follow certain procedures for expected solutions with the absence of problem exploration stage. In addition to the open-ended lab modules, course instructors formed online lab groups through which students shared the entire problem-solving process from ideas formation to solutions through trial and error.

To investigate the effectiveness of the open-ended online lab learning experiences, students in all courses were randomly divided into experimental and control groups. Students in the control group learned in labs through learning materials that are aligned with core concepts by following a completed given procedures students in the experimental group learned through inquiry-based labs learning materials that required them to work in teams by integrating core concepts together to find solutions with multiple approaches. To maximize the online lab learning effect and to replicate the way industry, commerce and research practice, instructor structured cooperative learning strategies were applied along with pre-lab simulations and videos.

The research results showed that generally students in the experimental group outperformed their counterparts in labs especially with more advanced concept understanding and applications, but showed mixed results for the overall class performance based on their course learning outcomes such as quizzes, lab reports, and tests. Further, survey results showed that 72% of students reported open-ended lab learning helped them learn better. According to interviews, the initial stage of working with team members was somewhat challenging from difficulties in finding time to work together for discussion and problem solving. Yet, through many communication tools, such as course LMS and mobile apps they were able to collaborate on lab problems, which also led them to build learning communities that went beyond the courses.

1. Introduction

During the last decade, there has been a significant increase in demand both from students and industry to shift away from traditional education and move toward a more independent method of online learning [1-5]. Accordingly, higher education institutions have been introducing and expanding online courses and online labs to meet this demand. The recent pandemic outbreak has necessitated this transition rather than being an option. As a result, it has brought forth numerous challenges to the learning environment. Among many challenging issues arose in the process of the transition, helping undergraduate students with their learning in their online laboratory experiments is an important one to tackle, especially in electrical engineering (EE) programs where laboratory work in introductory courses is integral part of the discipline.

Until very recently, lab courses stayed as a main obstacle when offering a fully online electrical engineering courses [6-9]. In order to address this challenge, engineering colleges made attempts to solve the problem by replacing the lab work with software simulations, which can help students to reinforce concepts, practical experiments are critical for EE undergraduate education to develop the students' skills in dealing with the real instrumentation [10]. Despite the effort, simulations alone cannot adequately train students to solve problems that students may see in an actual lab nor provide adequate hands-on experience necessary for effective learning [11].

One solution to having online laboratories in EE has been the use of lab-in-a-box approach [12], through which students can have hands-on design experience by using a portable and affordable test and measurement device, such as the Analog Discovery kit. Comparable to the price of engineering textbook, EE students can have their own labs wherever they are and can work on it at their convenience. This is a portable hands-on lab where students can build circuits using resistors, transistors, microchips, to name a few, and also collect waveforms, data, and analyze the results. Using the lab-in-a box approach, the project team and other faculty in the EE program started offering our first 100% online laboratory of circuit's lab a few years ago. Soon after, we were able to successfully convert all lab learning portions of EE from the conventional laboratory platform to virtual labs.

This lab-in-a-box approach enabled students to learn EE concepts through hand-on experiments virtually, and it turned out to be instrumental for many of our EE students who took co-op and internship opportunities because it allowed them to complete their education while learning on the job and graduating in four years. Moreover, the EE virtual lab experiences have much more possibilities without being limited to lab courses. The project team and faculty in EE successfully integrated laboratory experiences into purely theoretical courses via Hardware-in-Homework (HiH) concept [13, 14]. The Analog Discovery kit is a good example of HiH, which can play an important role for students who learn EE materials in an online setting. The unique measurement features of the Analog Discovery kit can be appropriately applied to lower to upper-level courses [14]. Due to its readily available and portable nature, it will be beneficial for students who learn well with hands-on activities.

With a growing need of an integration of online labs in engineering curriculum, it is imperative that we study the effectiveness of online lab experiences with the goal of improving student success and self-efficacy. Online lab sessions must offer active learning experiences, which may include ample opportunities for students to interact with their peers and instructors, and tackle real problems by experiencing trials and errors. This research on the online labs can greatly contribute to enhancing EE engineering student learning. Further, it will address the critical component of EE engineering - experiential learning - with a lot of hands-on lab learning experiences that can lead to a deeper understanding of engineering concepts. Well-designed online labs can help students maintain enthusiasm for engineering fresh and can also increase the retention rate for engineering students [15].

The goal of this project is to develop high-impact online lab teaching practices and to test their effectiveness of them. Accordingly, during the two long semesters in 2022, we tested our innovative online lab teaching strategies in the laboratory sessions with the following active learning strategies in the laboratory sessions by a) developing and implementing open-ended design experiences into lab work, b) establishing teamwork in online labs, c) creating an online learning community and to overcome isolation, and d) incorporating pre-lab simulations and pre-lab video demonstrations. These core lab learning strategies were applied in five EE courses: Circuits, Electronics I & II, Microcomputers, and Signals and systems. Having advanced hands-on lab experiences in these courses can play a critical role for students who will take their senior capstone design course in which they need to demonstrate their understanding of key EE concepts. This is essential not only for understanding concepts and application skills but also for learning to collaborate with peers through ample experience of trials and errors in their lab learning, which will enhance their collaboration skills as well as critical thinking skills.

2. Study Intervention

We have implemented various learning strategies to improve the quality of EE online engineering labs, and the detailed explanation is below.

A. Introducing open-ended design experiences

The inclusion of inquiry-based learning strengthens an engineering curriculum, as real-world engineering is best approached on an inquiry basis [16]. Active-learning methods such as inquiry-based learning shift the locus of control from the instructor toward the student. It can improve creativity, critical thinking skills and knowledge acquisition by employing open-ended questions [16, 17]. In the last two decades, there has been a strong movement toward more active-learning inquiry as there is evidence that it helps students learn, engage, and become more confident [17-20]. In a traditional laboratory, students follow given procedures to obtain pre-determined outcomes by having them manipulate equipment, learn standard techniques, collect and interpret data, and write reports. However, the drawback of this method is the lack of critical thinking skills. A study has shown that an open-ended laboratory can increase student independence by giving them the opportunity to be innovative and creative in designing and executing their own experiments [21].

Rather than giving students a "cookbook" approach where they are guided step by step with instructions, the open-ended (O-E) design experiences can provide students opportunities to explore and figure out solutions for a set of problems collaboratively. This approach especially in online labs can eliminate feelings of isolation as it prompts collaboration among peers. In this process, students will discuss multiple pathways for problem solutions. Besides decreasing or eliminating feelings of isolations, we surmise that students will develop better experimental skills with an understanding that there can be many alternatives to address a given problem. Further, increased sense of connectedness can contribute to attracting and retaining students to the BSEE program by increasing student self-confidence, providing opportunities to instill self-reliance, developing deeper understanding of fundamental concepts.

It is expected that the O-E lab activities will encourage students to become actively involved in each lab, facilitate a dialog with the instructor and each other, and enable teamwork [20]. In O-E laboratory experiments, learners are provided with clear objectives and a problem statement; however, the laboratory procedures necessary to complete the objectives will only be outlined in broad terms. Learners need to develop the procedures through literature search or going through textbooks. They also need to identify the various parameters and data that need to be collected [22]. Students will be designing and executing their own experiments while gaining self-confidence.

Balancing the number of O-E design labs and the timing of these labs are important to help student successfully solve problems [23]. Therefore, we have structured the labs such that the focus of student learning shifted from prescribed experiments to O-E laboratories in order to ensure that students learn basics before designing the experimental procedure. We have incorporated three O-E design labs for each course by giving two weeks to complete each open-ended lab. We intentionally planned for an extended lab learning time for online labs than the ones in person due to the inherent communication difficulties for students in online learning settings. Below are two O-E lab samples taken from Electronics II and Circuits I courses (only a portion of each lab is shown):

1) *MOSFET Common Source (CS) Amplifier Design (Open-ended Design Lab-Electronics II)*

   a. Based on the CS amplifier shown in Fig. 1, derive formulas for -3dB frequencies f_L and f_H. Assume that the load capacitor is very large compared to parasitic transistor capacitance.

b. Design the amplifier shown in Fig. 1 using Multisim simulation tool. Use a ZVN2110A NMOS transistor and take R_D=0.25k. In designing for the biasing resistors R_1 and R_2, there must be three criteria that need to be satisfied:

- The DC voltage value at the gate terminal should be such that the output DC voltage V_{DS} equals to $V_{DD}/2$.
- The input resistance of the amplifier should be more than 1k. There are multiple solutions to this problem.
- You should realize resistors R_1 and R_2 based on the values in component box with minimum number of resistors combined (e.g. combine up to 2 resistors)

c. Once you determine the values of resistors R_1 and R_2, verify that amplifier works as intended (use Multisim) and do a gain calculation (use a suitable coupling capacitor).

d. Design the amplifier such with cut-off frequencies of f_L=178 Hz and f_H=637 kHz. Use formulas you derived in pre-lab. Include bode plot, circuit schematics and your findings.

e. Construct the circuit of Fig. 1 on your breadboard and run the circuit using Analog Discovery module. Obtain the Bode Plot using the Network Analyzer tool.

f. Lastly, compare your hand calculation results to results derived from simulations and Analog Discovery measurements. If there are any discrepancies in corner frequencies, state possible reason(s) for the error.

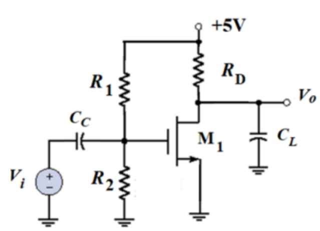

Fig. 1 Common Source NMOS Amplifier with a load capacitor

2) *AC Circuits (Open-Ended Design Lab part-1 Circuits I)*

Referring to the circuit given below in Fig. 2, a sinusoidal voltage source with its value shown is connected to impedance (a passive circuit). The circuit current $i(t)$ is measured to be $i(t)=0.018 \sin(2\pi(8{,}625)t + 42.71^{\circ})$

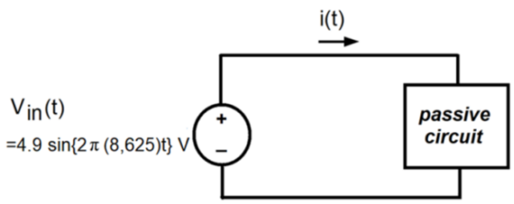

Fig. 2 AC Circuit impedance lab

a. Design a circuit that would produce the specified current magnitude and phase when the specified V_{in} source is connected to the input. Use either a series R-L or R-C circuit whichever applicable and obtain the desired phase shift given. Use the component values given in your ADALP2000 box (e.g. resistors, inductors or capacitors), but you can combine components in parallel or in series to get desired values.

b. Perform a Multisim simulation of the circuit designed and indicate how current waveform maximum and phase values match to your hand calculation results. For the current waveform, use the resistor voltage in scope and scale it properly to obtain the current waveform.

c. Construct the designed circuit on breadboard and obtain the input and output waveforms using Analog Discovery. Your output waveform would be the current waveform. In Analog discovery, use a "Math channel" to plot the current waveform.

d. Compare your experimental results to hand calculation and simulation results. If experimental values do not match well, measure the exact value of resistance, capacitance/inductance (whichever applies) with a multimeter and use the exact value in your experiment. As an example if a resistor value measures less than anticipated, you may add an additional series resistance to match the actual value. Repeat the experimental part in c.

B. Accomplishing teamwork in online labs

Implementing inquiry-based labs often goes hand-in-hand with implementing collaborative and/or cooperative learning strategies [24, 25]. Instructors that employ inquiry-based learning in conjunction with cooperative learning in their classes might expect positive student attitudes and high levels of learning [25, 26]. Cooperative learning is an activity often outlined by instructors as to what students do and how they work together in small groups. Even though this instructional strategy would be a good fit for lab works, typical online labs using the lab-in-a-box approach usually requires each student to do the work alone. Students in this approach, unfortunately, may miss the feeling of shared accomplishment and collaboration. As a solution to this challenge, we surmise that students can learn better by discussing and proposing alternative problem solutions when they learn in teams, which will prompt them to experience trials and errors with their team members. This learning format of virtual teamwork replicates the way engineering industry and commerce function every day worldwide [27]. Moreover, working in teams can results in a better understanding and retention of course materials, higher motivation for learning and lower attrition rates in online learning [26, 28].

For the EE courses we identified, we have formed virtual teams of three to four students in each team. At the beginning of the semester, students were instructed that each member's task distribution should be discussed and decided as equally as possible to ensure individual accountability. The responsibility were to be identified in their team lab reports. Each team was told to accomplish their shared goals by working together, but each student should contribute to solving problems utilizing his/her experience and understanding of the techniques. Students were asked to submit the task distribution and responsibilities to the instructor prior to each O-E design lab activity. This project is reflective of the adopted instructor-structured cooperative learning strategies that include assigning roles to members of each group, rotating roles periodically, allowing team member's rate each other's contributions and group accountability. On the team reports, students were instructed to outline the steps taken to arrive at solutions, potential alternatives, and limitations, much like a standard Senior Project design.

In addition to team lab reports, team presentations were also part of their learning activities, and they were asked to include the following in their presentation:

- Approaches taken to solve problems
- Problem solving steps

- Thinking process addressing challenges, mistakes, and correcting processes to reach to conclusions
- Final products

Each team presented their work using a video conferencing tool, Blackboard Collaborate, which includes virtual classroom and online meeting spaces to share presentation materials by allowing students to communicate and collaborate among them and faculty via live audio, video, and chat tools. The course instructors in this project provided presentation time slots to students to allow them to select their team presentation time during the designated presentation week. Each team was given approximately 15 minutes to present their work. After the lab work and the team presentation, students were asked to rate each other based on the areas below and the average rating got reflected in their overall lab score:

- Did the team member complete his/her task in a timely manner?
- Is the member's solution or contribution acceptable?
- Did the team member attended team meetings and interacted with other members in a responsible matter?

C. Overcoming the sense of isolation by creating learning communities

In order to ensure active learning, online lab sessions should offer frequent opportunities for students to interact with their peers and instructors and to work on real-life problems [6]. Learning management platforms such as, Blackboard Collaborate, provide many learning tools that can create and facilitate learning communities for labs and allow for interpersonal communication exchanges that often lead to deeper meaning and understanding. Incorporating interactive course features, such as discussion boards or chat tools can elicit voices from each student, and it creates learning environments where students can feel they are part of learning communities even though they may not have in-person interactions.

We have made extensive use of course discussion forum and Blackboard Collaborate tools to create a learning community. Instructors have attended the discussion forum almost daily for questions. Based on our experience, it is important for instructors to initiate the discussion for each lab. This encouraged students to engage more in the discussion. In all three classes studied in this project, the participation in the discussion forum contributed to 10% of their lab grade. For each lab, they needed to do 3 or more postings or interactions to earn the discussion grade. With the discussion forum, students often helped each other on circuit troubleshooting and the experimental procedures without any need for an instructor or the TA to intervene. To some extent, this active class discussion functioned as the lab chat that can occur during traditional, in-person labs.

Students have used Collaborate tool not only for their presentation but also to interact with their course instructors to seek help for their O-E designs. We believe the frequent use of collaboration tools can enhance the sense of connectedness among peers and sense of belongingness. To increase learning communities even further, we also had our students interact with a group forum that includes our entire EE undergraduate cohort, which is organized for all EE courses during their first year of study. This can allow our students to interact with all levels EE students and with other instructors. Improvements in both areas of connectedness and belongingness can perhaps increase student retention [28], which will be monitored for the multiyear data.

D. Incorporation of pre-lab simulations and pre-lab video demonstrations:

Previous studies have indicated that students feel more prepared for laboratory classes when online pre-lab activities are available [29]. Students have also reported that the online pre-lab material had a positive effect on their learning that they were able to enter the laboratory with high levels of perceived preparedness [30]. Simulation work as a pre-lab can give students knowledge and some confidence because of the exposure to a direct experience of something they will encounter in an actual experiment. The simulations allow students to attempt the experiments they will do in the laboratory in a risk-free way that provides the opportunity to make mistakes and learn how to correct them using the immediate feedback generated. It was reported that the simulations have contributed to increased knowledge attainment and improvement in student confidence level [31].

Pre-lab video demonstrations can help ease the frustration students often experience in labs; therefore, they can increase the confidence to carry out the activities during online lab sessions [30]. Hence, most online labs in selected lab courses in this study have been enhanced using pre-lab simulations and pre-lab video demonstrations. While most simulations provided a worry-free experience before actual implementations, some simulations were used in actual design process. Pre-lab videos for team labs included overview of specifications, general guidelines for the implementation. The non O-E design labs were accompanied with theory, details on the procedure, and some expected results.

3. Project Assessment

To examine the effectiveness of the open-ended labs and its implementations, we conducted experimental research by forming two lab groups in the five courses in this study: Circuits I, Electronics I, & II, Microcomputers I, and Signals & Systems. All courses were offered online. A total of 121 students who were enrolled in those five courses were the study subject, and male students were the majority (88% male and 12% female). Students were randomly selected into either experimental group with the open-ended labs or control group with traditional lab approaches. Each group comprised of four to five students, and it remained the same throughout the semester.

a. Student Demographic Information

To better understand student demographic information, we collected data through a survey. We had approximately 60% students responded. The majority of students preferred taking courses online (60%), some wished they took courses in-person (23%), and the rest did not have any preference (9%). Regarding their classification, the majority of the students were juniors and seniors (seniors 33%; juniors 60%; sophomores 8%; freshmen 0%). The average credit hours enrolled for students were 14 (SD=2.43), and most students (67%) indicated that they were employed, and 36% of them specified that their work was not academically relevant at all.

b. Student Learning Outcome Results

When we examined the overall academic performance through all modes, such as class quizzes, exams, discussions, and lab reports, the learning outcomes showed mixed results, as can be seen in Table 1. However, when we examined student performance in the laboratory only, students in the open-ended labs showed generally higher scores than students in the traditional labs. In the in-dept look at student performance with advanced concepts in each course, students in the experimental group outperformed their counterparts, as can be seen from Table II. The learning outcome difference is quite noticeable in Electronics and Signals and Systems by showing quite higher average scores for students in the experimental group than those in the control group.

Table I. Overall Student Learning Outcomes

Course Name	Average Scores Across All Instruments (exams, labs etc.)		Lab Average Score	
	Experimental Group	Control Group	Experimental Group	Control Group
Circuits I	76.78 (N=9, 2F)	78.76 (N=11, 2F)	90.88	87.22
Electronics I	71.57 (N=11, 2F)	73.95 (N=7, 0F)	82.10	88.90
Electronics II	84.44 (N=14, 0F)	76.29 (N=14, 0F)	92.24	71.49
Microcomputers I	56.62 (N=12, 2F)	57.00 (N=14, 2F)	94.13	89.30
Signals and Systems	81.7 (N=14, 1F)	84.1 (N=15, 3F)	81.70	89.90
Total Number of Students	60	61	60	61

*F indicates female students

Table II. Overall Student Learning Outcomes with Advanced Concepts

Course Name	Experimental Group	Control Group	Key Concepts
Circuits I	83.3	80.7	AC impedances
	83.3	78.8	RL/RC Transients
Electronics I	59.0	47.0	Amplifier Design
Electronics II	90.1	82.1	Frequency Response
Microcomputers I	58.3	50.0	Shifts in Assembly Instructions
Signals and Systems	92.6	86.7	Characterization of Discrete Signals
	92.9	66.7	Fundamental Frequency of Periodic Signals

Besides learning outcomes, it is also documented that students in the experimental group showed more active participation in class discussion than their counterparts based on their frequency of communication using discussion forums. Further, some students saw benefits of collaboration with open-ended lab modules not only for concept understanding, but also for communication skills. Below are direct quotes from team lab reports from experimental groups:

> *"When working in a group, you gain the opportunity of brainstorming amongst each other. When the need to address a problem within the lab occurs the quality of the solutions can increase due to their collaborative efforts. Additionally, you're allowed a more in-depth understanding of each portion of the lab due to the time spent figuring out the challenges of your responsibilities." – Team Lab Report from Electronics I*
>
> *"I believe the ability to cooperate with other students in an online environment has created the opportunity to not only allow growth in comprehension of the topic, but communication skills are sharpened as well." – Team Lab Report from Electronics II*

Because students had to work together on their lab reports, students in the experimental group seemed to stay connected with their peers through the course learning management site as well as other communication tools. During the interview, some students said that they exchanged phone numbers for texting and used video conferencing platforms, such as Zoom or Discord.

According to students in the experimental group, time management and group dynamics were two most frequently mentioned challenges they experienced. Through interviews and surveys, students said that finding time for all group members could work on lab experiments, reports, and presentations was one of the challenges because almost seventy percent of students were working, and some students had family to take care of at the time of this study.

> *"Group work presents its pros and cons. Adjusting around other people's busy schedules was the most challenging aspect of working in a group not for my Signals and Systems class."*
>
> *"In electronics, I was in the experimental group, and it was kind of difficult at first, honestly, to figure out how to divide up the lab to make it work because my other two*

classmates that were in my group, one of them, worked full time and barely ever had time to help with anything."

In addition to time management, group dynamics was mentioned as another challenge when students worked with group members. The challenge ranged from group members having varying levels of content knowledge preparedness, willingness to participate, being individually and collaboratively accountable for bringing lab problem solutions. Below are some quotes that show this view:

"Groups are great if you get a group with members that do their part. These labs were more everyone can do a section with little or no interaction with the other members other than questions if you get stuck. A lab that would rely on the other members input would not go well if certain members won't do their part."

"I think lab groups both have pros and cons. Sometimes not all members participate properly. It was really challenging trying to set meet up times with my group, they would just try to do the lab like if it was an individual lab instead of a group lab."

Even though students faced many challenges such as time management and group dynamics, after students successfully completed lab experiments together as a group, some students formed learning communities and saw the benefit of working together by dealing with faced challenges.

"After several group labs, I feel like the teamwork is beneficial to us, as it gives us a head start to the any industry. Having objectives done in a collaborative effort allows us to experience the creative ways our teammates approach towards problems and creative ways we can come up with solutions to solve these problems."

"The one thing that was nice was that we had a group chat, and we were able to just ask questions in there and figure things out together, which was a lot nicer than with like a one person lab or like, individual lab, because it was nice to have these people that you could go and ask if they know what you're talking about, and you're not just doing it by yourself."

4. Conclusions and Future Work

Students who learned in the open-ended laboratory approach in an online setting showed generally better learning outcomes than their counterparts in the traditional laboratory setting especially with advanced concepts. Despite the generally positive learning outcomes, student perceptions regarding their laboratory settings were mixed. Some students preferred the traditional laboratory setting with step-by-step approaches whereas some students preferred the open-ended laboratory approach which involved problem solving group discussions, presentations, and idea sharing through various communication tools. The data through survey and interview revealed, however, that student preferences were not necessarily tied to their learning outcomes. In fact, some students stated that they learned so much by solving problems together in the open-ended laboratory setting and they built learning communities because they learned to work together. For future work, we will continue to perform formative and summative assessment to improve the open-ended laboratory modules and its implementations. Further, we will also conduct more in-depth assessment and evaluation with students and will follow-up on the long-term effect of the current research project on students learning.

Acknowledgment

This project is sponsored by the National Science Foundation grant #2048328.

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