Creating Engaged and Active Learning Through Collaborative Online Lab Experiences

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***Abstract*— This innovative practice paper describes how we implement active learning through collaborative online laboratory experiences as a work in progress. The goal of our project is to develop and implement various instructional tools and learning strategies in order to improve the quality of electrical engineering online labs. The applied strategies include integration of open-ended design experiences into lab work, accomplishing virtual teamwork, creating an online learning community and overcoming the isolation, incorporation of pre-lab simulations and videos. We believe that active learning labs will help students develop a deeper understanding, build self-confidence and improve critical thinking skills while increasing the sense of belonging in the field of engineering.**

Keywords—Active learning, virtual teamwork, online labs, electrical engineering, open-ended labs

I. 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]. Higher education institutions have been introducing and expanding online courses and online labs due to cost and demand.

The recent rapid transition of learning environments from traditional college classrooms to online spaces in the wake of COVID-19 has given faculty little time for planning and preparation. Challenging issues arose, particularly in online engineering laboratory courses for undergraduates. Engineering labs can be taught effectively online with effective strategies. The good practices developed for online lab delivery is timely and it has many implications for other modes of learning environments.

The majority Electrical Engineering (EE) programs include laboratory work in introductory courses, such as circuits and logic design and lab classes as they are integral part of in the engineering curricula. Until very recently, lab courses stayed as a main obstacle in offering a fully online electrical engineering degree [6]-[9]. In order to alleviate the problem, engineering colleges proposed software simulations to replace the lab component. Although simulation may be used to reinforce concepts, practical experiments are critical for EE undergraduate education to develop the students' skills in dealing with the real instrumentation [10].

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In addition, simulations alone do not adequately present 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.

In the Lab-in-a box approach [12], students can have hands-on design experience by using a portable and affordable test and measurement device, such as the Analog Discovery. Comparable to the price of engineering textbook, EE students can have their own labs at their convenience. This is a real, hands-on lab where students build circuits using resistors, transistors, microchips, to name a few, and also collect waveforms, data, and analyze the results.

In 2014, we have succeeded in offering of our first EE online laboratory (circuit's lab) using the Lab-in-a-box approach. This was an important milestone as it allowed a completely online lab experience. Following this, all remaining lab courses have been successfully converted to online labs.

After the creation of all of our online labs, our EE program began content delivery in *Digital eLearning format* in the following year. Our Content Delivery system relies heavily on Blackboard and includes closed-captioned videos, tutorials, lecture slides, discussion forums, assignments and most importantly our online labs. While our hybrid program has face-to-face component, we allow some of our students to be hybrid-exempt or online. This system has been instrumental for EE students who have taken co-op and internship opportunities because it allows them to complete their education while learning on the job and graduating in four years.

Our students' lab experiences are not just limited to lab courses. Starting in 2016, we have integrated laboratory experiences into purely theoretical courses via Hardware-in-Homework (HiH) concept [13], [14]. Since our students purchase Analog Discovery kit during their freshman year as part of their course enrollment requirement and use it across many EE courses, the HiH concept came at no additional cost to them. The unique measurement features of the Analog Discovery makes it appropriate for upper-level courses as well [14]. Many of our engineering students are "experiential" learners, who learn by doing, thus students acquire a deeper knowledge through hands-on experiences. This would allow courses that either never had a lab experience or lost the lab experience to result in a value added lab experience.

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 on improving student success and self-efficacy. Online lab sessions must offer active learning experiences, which may include frequent opportunities for students to interact with their peers and instructors, and tackle real problems. The improved quality of labs would greatly contribute to the student success, since many of our engineering students are "experiential" learners who learn by doing and acquire a deeper knowledge through hands-on experiences. This would keep their enthusiasm for engineering fresh and can also increase the retention rate for engineering students [15].

We have developed high-impact online lab teaching practices that are instrumental for teaching online labs and implemented the following active learning strategies during spring 2022 semester: a) integration of open-ended design experiences into lab work, b) accomplishing teamwork in online labs, c) creating an online learning community and overcoming the isolation, d) incorporation of pre-lab simulations and pre-lab video demonstrations.

These strategies have been implemented in the following three courses during the 2022 Spring semester: Circuits I, Electronics II and Signals and Systems. We selected these courses because they play a critical role for students in developing advanced hands-on skills needed before they take the Senior Capstone Design course during their final year as engineering major students.

We believe that these active learning lab strategies will have a significant impact on improving students' self-reliance, critical thinking skills and knowledge retention. They will also increase their motivation and attitudes towards electrical engineering majors. In this work-in-progress paper, we describe the active learning lab strategies and discuss on the implementation details.

II. Active Learning Labs

We have implemented various learning strategies to improve the quality of EE online engineering labs.

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 lacks 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].

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 the 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, understand that there can be many alternatives to address a given problem. Further, increased sense of connectedness can contribute to attracting and retaining students in 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 working together as a team [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 some 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.

The balancing the number of O-E design labs and the timing of these labs are very critical for student's success [23]. Therefore, we have structured the labs such that the focus of student learning shifted from prescribed experiments to O-E laboratories. This is done to ensure that students learn basics before designing the experimental procedure. We have incorporated three O-E design labs for each course. Students were given two weeks to complete each open-ended lab due to increased scope of these labs. The difficulty of open-ended design labs were such that we were able to assign them to virtual teams. 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 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.

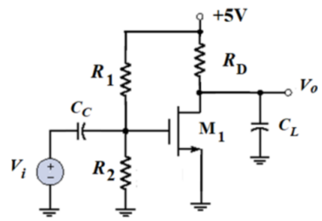

Fig. 1 Common Source NMOS Amplifier with a load capacitor.

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 (2π(8,625)t + 42.71°)

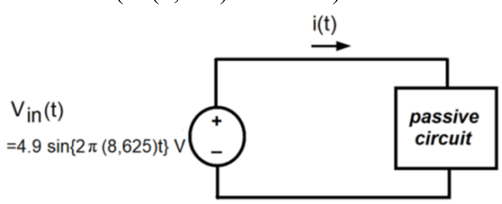

Fig. 2 AC Circuit impedance lab.

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.

b) Perform a Multisim simulation of the circuit designed and indicate how current waveform maximum and phase values match to your hand calculation results.

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. Repeat the experimental part in c (e.g. after adding a small resistor) .

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].

Online labs using lab-in-a-box approach usually requires each student to do the work alone. Unfortunately, students in this approach may miss the feeling of shared accomplishment and collaboration. Students learn better in teams and find it a more enjoyable learning experience.

Virtual teams replicate the way industry, commerce, and research practice every day worldwide [27]. Working in teams 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 three EE courses, each course instructor has randomly formed virtual teams consisting of at most three students and open-ended design work has been divided among students. Each student has contributed to solving the problem utilizing his/her experience and understanding of the techniques. We have used 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.

At the beginning of semester, students were communicated that each member's responsibility should be stated on team lab report and the task distribution should be as fair as possible. They were asked to submit the task distribution and responsibilities to the instructor prior to each O-E design lab activity. 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 the problem.
- Problem solving steps and the thinking process addressing challenges, mistakes, and correcting processes to get to conclusions
- Final products

Following report submissions, each team presented their work via "Blackboard Collaborate" tool after picking one of the presentation time slots given by the instructor. The Collaborate platform 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. Each team was given approximately 15 minutes to present their work. Team members rated each other based on the areas below and the average rating got included in the lab score:

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

With clear expectations and performance rubric for the group presentations, students delivered outcomes citing clear evidence of successfully accomplished teamwork, according to the course instructors' observation. On the team reports, students have outlined the steps taken to arrive at the solution, highlighted potential alternatives and mentioned the limitations, much like in Senior Project design course.

Table I shows the sample lab grading policy used for open-ended design labs. Lab report product makes 55% of the total lab grade for each student. Each team member presents his/her part in Collaborate and earns a presentation grade of 10%. Another 10% comes from teammate scoring. Then, a 15% of the lab grade comes from team's ability to complete the task in a timely manner to obtain an acceptable product. Last grading item on Table I is the discussion forum posting where each student needs to engage as part of his/her lab grade. This is part of our third strategy which will be discussed next.

TABLE I TEAMMATE PARTICIPATION RUBRIC

Team Lab Report Product	55%
Discussion forum Posting (each member needs to engage)	10%
Team presentation (each member is graded based on his/her part)	10%
Team members rating each other	10%
Team's ability to complete task together in a timely manner to obtain an acceptable product	15%

C. Overcoming the isolation of the online labs and 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]. Platforms such as Blackboard Collaborate and discussion forums can create a learning community for labs and allow for interpersonal 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 (such as virtual rooms, audio/video chat 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, and 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 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.

III. STATUS

We are currently in the process of examining the effectiveness of the instructional improvements in three online engineering classes as well as online lab sessions. Three means of assessment are currently being used in the analyses: results obtained from the project using pre- and post- surveys and data obtained on the ABET student learning outcomes using various course assessments, such as lab reports, exams, quizzes and homework assignments. We are seeking answers to the following research questions:

- Do the collaborative online labs improve students' learning in the chosen EE courses?
- How much better will be the performance of students taking collaborative online labs compared to their counterparts in conventional courses?
- Did the open-ended design problems given in labs help students develop a deeper understanding; build self-confidence and improve critical thinking skills?
- How does a collaborative learning community help students' learning experience?
- Is there a difference in students' interest, self-efficacy, motivation and attitudes toward EE for those who receive the collaborative online labs, compared to those who received the online labs before the lab strategies implemented?

IV. CONCLUSION

We believe that the implemented enhanced laboratory experiences will contribute to the improvement of multiple ABET student learning outcomes as well as student learning experiences. The methods used in this study to enhance the laboratory experience are applicable to other STEM disciplines as well.

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