Online Electrical Engineering Labs with Collaborative Open-Ended Assignments

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***Abstract*— This innovative practice paper describes our implementation of open-ended (O-E) collaborative lab assignments as a work in progress. It provides details on the O-E collaborative lab assignments, shares some examples of O-E labs used, and reports the results of the first year of implementation. We believe that open-ended collaborative 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— Open-ended labs, Active learning, virtual teamwork, online labs, electrical engineering

I. Introduction

Over the past decade, there has been a considerable rise in demand from students and industry to shift away from traditional education by adopting a more self-directed online learning approach [1]-[5]. Higher education institutions have been introducing and expanding online courses and labs due to cost and demand, and this trend got accelerated with the pandemic, rendering it a necessity rather than an option. Yet, this transition presented numerous challenges to the learning environment. Among many, providing effective online lab learning environment remains challenging, especially in Electrical Engineering (EE) programs where laboratory work in introductory courses is integral part of the discipline. Until recently, lab courses stayed as a main obstacle in offering fully online EE degree [6]-[9]. Software simulations have been used as an alternative to address this issue. Despite the effort, simulations alone cannot adequately solve problems that students can learn in an actual lab nor provide adequate hands-on experience necessary for effective learning [10], [11].

Addressing the challenge of providing effective online lab learning environment is critical and timely. An approach that has been introduced to enable online laboratories in EE involves utilizing the "lab-in-a-box" method [12], which allows students to gain hands-on design experience by using a portable and affordable test and measurement device, such as the Analog Discovery. 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.

The lab-in-a-box approach can enable students to learn EE concepts through hand-on experiments virtually, and it turned out to be instrumental for students with co-op and internship opportunities because it allows them to complete their education while learning on the job and graduating in four years. Moreover, EE online lab experiences have much more possibilities without being just limited to lab courses. We 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, and its unique measurement features can be appropriately applied to lower to upper- level courses [14].

Although the lab-in-a-box approach can provide hands-on skills, it requires students to work in isolation, which omits teamwork that is crucial for EE students. To address this critical, yet missing element, open-ended (O-E) design experiences can be implemented in online EE labs. In an O-E laboratory, students are given the liberty to design their own experiments, and they are prompted to collaborate with their peers. It can allow students to develop experimental skills and gain an understanding that there can be many alternatives to address a given problem. Through this approach students are challenged to think critically and creatively. Such teamwork can increase student independence by giving them the opportunity to be innovative and creative in designing and executing their own experiments. Well-designed online labs can help students maintain enthusiasm for engineering fresh and increase the retention rate for engineering students [15].

We developed fifteen O-E collaborative lab learning activity modules for the five EE courses: Circuits I, Electronics I, Electronics II, Signals and Systems, and Microcomputers I. These courses play a critical role for students in developing advanced hands-on skills needed before they take the Senior Capstone Design course. Within each course, three O-E design labs were utilized, with virtual teams consisting of at most three students. To facilitate collaborative learning, instructor-structured cooperative learning strategies were used in this study.

II. Open-Ended Design Labs

Incorporating inquiry-based learning into an engineering curriculum enhances its strength, as real-world engineering is best approached through inquiry [16]. Active-learning strategies, such as inquiry-based learning, empower students by shifting the control from instructors to students, leading to improved creativity, critical thinking skills, and knowledge acquisition through O-E questions [16], [17]. In the last two decades, there has been a strong movement toward more

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active-learning inquiry because it helps students learn, engage, and become more confident [17]-[20]. Moreover, an O-E lab with inquiry learning can increase student independence by giving them the opportunity to be innovative and creative in designing and executing their own experiments [21].

O-E design experiences provide students with opportunities to collaboratively explore and find solutions for a set of problems by discussing multiple pathways for problem-solving. This approach, particularly in online labs, helps eliminate feelings of isolation by fostering peer collaboration. Moreover, we believe that students will develop better experimental skills and gain an understanding that there can be many alternatives to address a given problem. Through explorative and collaborative O-E lab activities, students actively engage in each lab, facilitating dialogue with peers and instructors as they work together as a team [20].

In designing O-E laboratory experiments, it is expected that students are given specific objectives and problem statements, but the procedures to complete them are only broadly outlined so that they develop necessary procedures through literature search, and by identifying relevant parameters and data that need to be collected [22]. Balancing the number of O-E design labs and the timing of these labs are another important element 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 labs. This is done to ensure that students learn basics before designing the experimental procedure. In each course, we have included three O-E design labs, and due to the broader scope of these labs, students are given a two-week deadline to complete them. The complexity of the open-ended design labs is such that we were able to assign them to virtual teams. Below are two O-E lab samples taken from Electronics I and Circuits I courses:

1) Design of a Common Emitter Amplifier (Electronics I)

In this O-E design laboratory, learners are provided with the specific design criteria for the common emitter amplifier and only few component values specified. Based on theory they learned, they need to design the operating point as well as the biasing network of the amplifier. They will then build the circuit using Analog Discovery and verify amplifier operation.

In the final part of the experiment, learners need to design an experimental procedure to measure input and output impedance of the amplifier.

Neither the experimental procedure nor any figures are given to the learner. Learners need to develop the lab procedure after performing literature search or perhaps reviewing some textbooks.

a) You will first design the circuit of an emitter degenerated Common Emitter (CE) amplifier shown in Fig. 1. For this, you need to first determine the amplifier operating point and then design a resistor bias network at the base to provide the dc base voltage. Using Multisim, design the DC base voltage V_B such that the maximum gain is achieved.

Here, learners need to know that maximum gain is achieved when V_{CE} voltage is set at half the V_{CC} point. They also need to know how to perform a DC sweep simulation in Multisim to find the biasing point.

Design the voltage divider biasing to provide the required base voltage V_B. The only criteria is that the current thru R_1 (I_{R1}) should be large compared to the base current I_B. Make a reasonable assumption for the transistor current gain, $\beta = I_C/I_B$.

Based on the $I_{R1} >> I_B$ criteria, learners need to design the biasing resistors R1 and R2, by applying the theory learned. There is no unique solution to the values of these resistors; the answer for each student will most likely vary.

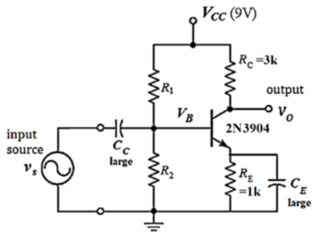

Fig. 1 Common Emitter Amplifier Circuit

b) 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. Choose appropriate values for both coupling and emitter bypass capacitors so that they won't affect the gain for frequencies higher than 1 kHz.

c) Perform a DC analysis using Multisim software and compute the small signal parameters. Utilizing these results, do a hand calculation of the voltage gain $A_v = v_o/v_s$, amplifier input and output resistances (R_i and R_o).

d) Determine the small signal input impedance R_i and then output impedance R_o via experimentation.

For this, learners need to design an experimental procedure to come up with input and output impedance measurement. For this, learners need to perform a literature search and/or review the learning material.

Fig. 2 shows a procedure that can be used for measuring the input impedance of the CE amplifier. For this, learners need to place a moderate value resistor (e.g. 1k) in series with the input AC source and measure the amplifier input voltage. Then, they should be able to come up with the input resistance value. For output impedance calculation, a variable resistor can be placed in series with the output and varied until voltage gain value reduces to 50% of the maximum. Neither the procedures nor the figures will be provided to the student.

e) Lastly, compare the gain values obtained through simulation and hand calculation with the measured value. Then, compare the results of input and output resistance measurements with the values obtained from hand calculation. If there are discrepancies, provide possible explanations.

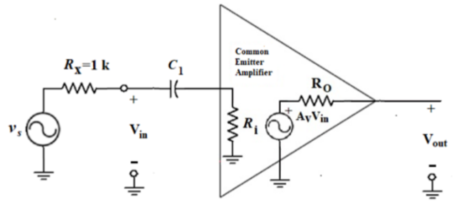

Fig. 2 Experimental setup needed for input impedance measurement

2) AC Circuits (O-E Design Lab part-1 Circuits I)

Referring to the circuit given below in Fig. 3, a sinusoidal voltage source with its value shown is connected to a passive load. The circuit current *i*(t) is measured to be *i*(t)=0.018 sin (2π(8,625)t + 42.71º)

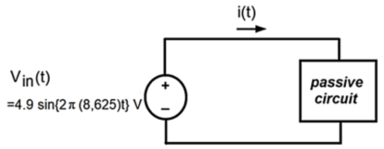

Fig.3 AC Circuit impedance lab.

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 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 the experimental values do not match well, utilize a multimeter to measure the exact value of resistance, capacitance, or inductance (as applicable) and attempt to incorporate the exact value in the experiment. Repeat the experimental part step *c*.

III. Accomplishing Teamwork in Online Labs

Inquiry-based laboratories are frequently accompanied by the adoption of collaborative and/or cooperative learning strategies [24], [25] because positive student attitudes and high levels of learning [25], [26] were reported. Therefore, we formed virtual teams consisting of at most three students and O-E design work has been divided among students. 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].

By adopting instructor-structured cooperative learning strategies in this project, we ensured that students remain responsible for their teams while individually accountable for their assigned roles. On the team reports, students were instructed to outline the steps taken to arrive at solutions, potential alternatives, and limitations, much like a Senior Project. Staying communicated during the teamwork is crucial, so various tools were used including Blackboard Collaborate virtual classrooms, meeting rooms, online discussion forums, and live audio, video, and chat tools. In addition to team lab reports, team presentation was an important part of their teamwork by including steps and approaches taken to solve problems, and thought processes to handle challenges to reach conclusions along with end products or outcomes achieved. After presentations, team members were asked to rate each other based on a rubric and the average rating got reflected in their overall lab score.

IV. First Year Results

To evaluate the effectiveness of the O-E labs and their implementation, an experimental research study was conducted in which two lab groups were formed for each of the five courses included in the study. A total of 121 students who were enrolled in the courses were the study subject, and male students were the majority (88% male). Half of the students were selected into either experimental group with the O-E labs and the remaining students were assigned to control group with traditional lab approaches. We have tried to equally distribute high performing students to both groups so selection of students into each groups were in a way pseudo-random.

1) Student Demographic Information

A survey was conducted to gather student demographic information, with around 60% of students responding. The majority of respondents were juniors and seniors (seniors 33%, juniors 60%, sophomores 8%, freshmen 0%). On average, students were enrolled in 14 credit hours (SD=2.43), and 67% of them reported being employed, with 36% stating that their work was not academically relevant.

2) Student Learning Outcome Results

Table I shows the experimental group and control group average scores for labs and across all instruments. 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 indicated in Table I. However, when we examined student performance in the labs only, students in the O-E labs showed generally higher scores than students in the traditional labs.

In the in-depth 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 Score Across All Instruments**		**Lab Average Score**	
	Exp. Group	Control Group	Exp. 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
Microcomp. 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

Besides learning outcomes, it was 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.

TABLE II STUDENT PERFORMANCE 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	Freq. Response
Microcomp. I	58.3	50.0	Shifts in Assembly Instructions
Signals & Systems	92.6	86.7	Characterization of Discrete Signals
	92.9	66.7	Fund. Frequency of Periodic Signals

Further, some students saw benefits of collaboration with O-E 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 stayed 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 platforms, such as Zoom or Discord.

According to students in the experimental group, the most common challenges they faced were time management and group dynamics. Through interviews and surveys, students mentioned that coordinating lab work, reports, and presentations posed difficulties, as nearly 70% of them were employed and some had family responsibilities during the 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*."

V. Conclusion

This paper presented our implementation of O-E collaborative lab modules, including examples and implementation results. Students in the online open-ended laboratory approach demonstrated better learning outcomes, especially with advanced concepts, compared to their counterparts in the traditional laboratory setting. However, student perceptions regarding their laboratory settings were mixed. While some preferred traditional labs, others favored open-ended labs involving problem-solving, group discussions, presentations, and idea sharing through communication tools. Interestingly, preferences didn't always align with learning outcomes, as some students learned more by solving problems together in open-ended labs and building learning communities by working together. For future work, we plan to conduct further formative and summative assessments to improve the open-ended laboratory modules and their implementations, as well as more in-depth evaluations with students to follow up on the long-term effects of the research project on their learning. We will also assess the impact of collaborative open-ended (O-E) lab assignments in upper level courses such as Senior Capstone Design course.

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