The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
ASEE
Paper ID #42546

Implementing Collaborative Online Lab Experiences to Facilitate Active Learning

Dr. Gleb Tcheslavski, Lamar University

Dr. Tcheslavski received his engineer-developer degree in Electronic Engineering from Bauman Moscow State Technical University and his Ph.D. in Electrical Engineering from Virginia Tech in Blacksburg, Virginia. At VT, he was a member of the Digital Signal Processing Research Lab. After graduation, he worked as a Post-Doctoral Fellow at University of Houston involved in Biomedical Image Acquisition and Processing. Currently, he serves as an Associate Professor in the Phillip M. Drayer Department of Electrical and Computer engineering at Lamar University.

Prof. Julia Yoo

Julia H. Yoo, Associate Professor in the Department of Educational Leadership and Teacher Leadership Graduate Program Coordinator at Lamar University.

Prof. Selahattin Sayil, Lamar University

Selahattin Sayil received the M.Sc. degree from the Pennsylvania State University, University Park, PA, in 1996 and the Ph.D. degree in Electrical Engineering from Vanderbilt University, TN, in 2000. He is currently a Professor in Electrical Engineering a

Implementing Collaborative Online Lab Experiences to Facilitate Active Learning

G. Tcheslavski, J, Yoo, S. Sayil

Abstract

Laboratory experience is among the key components in engineering education. It is highly instrumental and plays a significant role in students' knowledge building, application, and distribution. Learning in laboratories is interactive and often collaborative. On the other hand, students, who learn engineering through online mechanisms, may face challenges with labs, which were frequently documented during the recent pandemic. To address such 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 Embedded System, through which students gain solid foundation before advancing to senior design projects.

The two main incorporated strategies were Open-Ended lab design and Teamwork implementation. Open-Ended lab modules using a lab-in-a-box approach allow students solving lab problems with multiple approaches fostering problem solving both independently and collaboratively. This innovative lab design promotes 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 prescribed approach leading students to follow certain procedures that may lack the problem exploration stage. Additionally, course instructors formed online lab groups, so that students were sharing the problem-solving process – from ideas formation to solutions – with their peers.

To evaluate the effectiveness of the implemented lab strategies, students in the participating courses were randomly divided into experimental and control groups. Both assignment grades and students' feedback via surveys were used to evaluate students' learning. Participants in the control group were learning in labs through the materials that were aligned with core concepts by following predetermined procedures. Students in the experimental group learned through inquiry-based lab materials that required them to work in teams by integrating core concepts together to find a solution and while following one of potentially many

approaches. To maximize the online lab learning effect and to replicate the contemporary industry, commerce, and research practices, instructor-structured cooperative learning strategies were applied along with pre-lab simulations and instructional videos.

This paper showcases the outcomes of our 2nd year implementation of active learning laboratory strategies on the mixed population of online and face-to-face students. We observed that students in the experimental group generally outperformed their counterparts in labs and showed significantly higher results in the assignments addressing more advanced concept understanding and applications (grand average of 88.3% vs. 66.3%). Surveys also indicated that students saw the benefits of collaboration with Open-Ended lab modules not only for learning concepts, but also for improving their communication skills. Students were able to collaborate on lab problems through various communication tools, such as course Learning Management System (LMS) and mobile apps forming online learning communities.

We believe that that the implementation of open-ended collaborative laboratory strategies can assist students in cultivating a deeper comprehension, fostering self-confidence, and refining their critical thinking abilities, all while strengthening their sense of inclusion within the field of engineering.

1. Introduction

Online mechanisms offer specific benefits for engineering education. Flexibility and convenience, personalized learning, variety of learning techniques are often named among such potential benefits [1]. However, lab courses that are an integral part of most engineering disciplines are often perceived as an obstacle for converting the corresponding programs into online and hybrid formats [2] - [5]. While software-based simulations may alleviate this problem [6], simulations alone can rarely provide sufficient hands-on experience that is critical for effective learning [7].

On the other hand, the lab-in-a-box approach allows students to learn hands-on engineering skills, while using a portable and affordable yet versatile measurement device, such as the Analog Discovery kit designed for Electrical Engineering (EE) laboratories [8]. This device allows students to build circuits using a breadboard and various electronic components and test them with a variety of standard waveforms, while analyzing the results with traditional instruments, such as oscilloscope and spectrum analyzer, that are also included in this hard/software kit. Using the lab-in-a box approach, the project team and other EE faculty in the program have successfully converted Electrical Engineering laboratories from the conventional 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 students taking co-op and internship opportunities. It allowed them to complete their education, while learning on the job and graduate in four years. Moreover, the EE virtual lab experiences are not limited to lab courses only. The project team and faculty in EE successfully integrated laboratory experiences into purely theoretical courses via Hardware-in-Homework (HiH) concept [9], [10]. The Analog Discovery kit is well suited for HiH, which can play an important role for students learning 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 [10]. This kit is readily available and portable, so it can reach out to students, who learn better with hands-on activities. In the selected courses, we extensively used the Analog Discovery kit with a breadboard and electronic components, as well as other hardware in the combination with various software simulators.

Following the COVID-19 outbreak, the problem of incorporating online labs in their curricula is faced by many engineering programs. Therefore, it is imperative to design such labs in the format that facilitates students' success and self-efficacy. Students should have ample ability to interact with their peers and instructors, while being engaged in experiential learning with sufficient hands-on learning experiences leading to a deeper understanding of engineering concepts. Well-designed online labs can also refresh students' enthusiasm for engineering, as well as increase the retention rate for engineering students [11].

The goal of the reported project was to develop high-impact online lab teaching practices and to evaluate their effectiveness. We have developed the lab teaching practices that were designed with the following strategies: a) to integrate open-ended design experiences into lab work, b) to accomplish teamwork in online labs, c) to create an online learning community and overcoming the isolation, d) to incorporate pre-lab simulations and pre-lab video demonstrations. These learning strategies were applied in the five freshmen EE courses: Circuits, Electronics I &

II, Embedded Systems, and Signals and systems. These courses were selected since they are among the essential lab-oriented EE courses; they were instructed twice with the modified laboratory.

2. Active Learning Labs

In the course of the project, we have implemented the following learning strategies to enhance the EE online labs.

A. Integration of Open-Ended design

Inquiry-based learning can enrich engineering curriculum [12]. Among other active learning techniques, inquiry-based learning allows students to have more control over the learning process. Incorporating open-ended questions may improve creativity, critical thinking skills, and knowledge acquisition [12], [13]. Active learning gains popularity, since it helps students to learn, engage, and become more confident [13] - [16]. Rahman and colleagues suggest that open-ended lab-work can increase student independence by letting them to be innovative in designing their own experiments [17].

Instead of providing step-by-step instructions, open-ended (O-E) assignments result in a series of inquiries that guide students through one out of many correct approaches leading to the desired solution. Applied in online environment, this approach may also alleviate the feeling of isolation as it prompts collaboration among peers to discuss multiple pathways in solving the problem. We also maintain that, following this approach, students will develop better experimental skills and understand that there a problem may have many alternative solutions. The improved sense of connectedness can contribute to attracting and retaining students in the undergraduate EE program by increasing student self-confidence, providing opportunities to instill self-reliance, developing deeper understanding of fundamental concepts. We expect that the O-E labs will promote better students' involvement into the assignments and improve their communication with peers and instructors and thus the teamwork [16].

In the O-E labs, students are provided with the problem statement and objectives; however, the procedures to achieve them are only outlined in broad terms. The learners need to develop the specific procedures via a literature search or other inquiries. Following this approach, the students are designing their own experiments; therefore, building their self-confidence.

Balancing the number of O-E design labs and their timing is critical for student's success [18]. We have incorporated three O-E labs for each course. Students were given ample time to complete each open-ended lab due to the increased scope of these labs. The increased difficulty of open-ended labs allowed us to assign them to virtual teams of 2-3 students. Below are two O-E lab samples taken from Embedded Systems and Signals and Systems courses (only a portion of each lab is shown):

Embedded Systems: the assignment specifies the general requirements for how to select the values for the experiments. Based on the specific values chosen by the student, the results of prescribed calculations will differ resulting in multiple solutions to each problem. However, since the underlying mechanisms are same, students should arrive to the expected conclusion.

Objectives: To find out why no results over 255 are returned by your Raspberry Pi. We will be using the GNU Assembler, called "as" and Assembly language simulator. You need to find out whether the Raspberry Pi Assembly can handle values exceeding 255 or not.

1. Pre-Lab assignment:

Use the Assembly simulator https://salmanarif.bitbucket.io/visual/downloads.html to execute your codes and report the results. Write the Assembly language code that will return the results of the following calculations:

a) Select two numbers: one exceeding 255 and another number less than 255, such that their difference would be less than 255. Evaluate their difference.
b) Select two numbers both less than 255 but such that their product is larger than 255. Evaluate their product.
c) Repeat what you did in 3.2 but instead of outputting the result, store it in a register. Divide this stored result by a small number (you will need to use the code you developed in Lab 6). Select this small number such that the division result should be less than 255.

2. Experimental procedure:

In your Raspberry Pi, start the File Manager…

3. Open-Ended Task 1:

Use the GNU Assembler to execute your codes and report the results. Write the Assembly language code that will return the results of the following calculations:

a) Select two numbers: one exceeding 255 and another number less than 255, such that their difference would be less than 255. Evaluate their difference.
b) Select two numbers both less than 255 but such that their product is larger than 255. Evaluate their product.
c) Repeat what you did in 3a) but instead of outputting the result, store it in a register. Divide this stored result by a small number (you will need to use the code you developed in Lab 6). Select this small number such that the division result should be less than 255.

4. Open-Ended Task 2:

Write the Assembly language code that will return the results of the following calculations:

a) Using the GNU Assembler select two numbers less than 255 but such that their sum would be greater than 255. Evaluate their sum.
b) Using the GNU Assembler Repeat what you did in 4a) but instead of outputting the result, store it in a register. Subtract this number from itself.
c) Repeat what you did in 4a) and 4b), while using the Assembly simulator https://salmanarif.bitbucket.io/visual/downloads.html.

Signals and Systems: the assignment only gives general directions on how to select signal's parameters and generate them. The necessary down-sampling factor in O-E task 1 will depend on the chosen signal's parameters; therefore, each team will work on their unique problem and select the appropriate path out of multiple approaches to solve the problem.

Objective: to learn practical aspects of modifying sampling rate of discrete signals.

Equipment: Analog Discovery Kit (ADK), jump wires, a computer with installed ADK and Matlab.

Procedure:

For Open Ended Task 1 and Open Ended Task 2, you will need to use one signal generator and one channel of the oscilloscope. Connect the output of the waveform generator to the input of the scope: orange (no strip) to yellow (no strip) and orange with a white strip to black. Connect ADK to a computer via USB.

1. PreLab Assignment: A theoretical/Matlab problem

   Consider the discrete-time signal $x[n] = \cos\left(\frac{2\pi n}{7}\right)$.

   a) Theoretically derive the expression for the down-sampled (by the factor 2) version z[n] = x[2n]. How many samples per period would this signal contain?

   b) Theoretically derive the expression for the up-sampled (by the factor 2) version y[n] = x[n/2]. How many samples per period would this signal contain?

   c) Using Matlab, generate and plot all three signals for $-50 \le n \le 50$. Do NOT connect dots/samples.

2. Open Ended Task 1: Down-sampling a sinusoid.

   To accomplish this task:

   a) Generate an arbitrary sinusoid using the ADK and store its samples in a text file. Refer to Lab 6 for the details. Take a screenshot using Scope.

   b) Load the signal you have generated into Matlab. Plot the signal as a function of time and save the plot.

   c) The signal you have loaded is discrete. Knowing the length of the signal in samples and counting the number of its periods, estimate the number of signal samples per period. Is the Nyquist sampling rate is satisfied?

      Hint: functions “length” and “size” may be handy.

d) Knowing the current sampling rate (the reciprocal to the number of samples per period), estimate the down-sampling factor needed to reduce the sampling rate to the Nyquist value. Down-sample your signal with the factor approximating the one you have estimated (see the hint below). On the same axes, plot both the original signal and its down-sampled version. Do NOT connect the samples/dots! Save the figure for your report.

   Hint #1: Down-sampling consists of discarding the specific number of samples per period, while retaining the rest. It can be achieved by using the "colon notation" in Matlab.

   Hint #2: it may be easier to implement down-sampling with an integer factor.

e) On a new figure, plot both signals but this time, allow Matlab connecting the samples. This, to some extent, mimics the up-sampling procedure using the linear interpolation. Save the figure for report.

   Hint: up-sampling is the procedure that attempts to "recover" signal samples that were discarded while performing sampling or/and down-sampling.

B. Accomplishing teamwork in online labs

Inquiry-based labs are often accompanied with collaborative and/or cooperative learning strategies [19], [20]. Inquiry-based learning in conjunction with cooperative learning may result in positive student attitudes and high levels of learning [20], [21]. In the traditional engineering lab environment, small workgroups are often formed by the instructor to facilitate the collaboration. However, most online labs using the lab-in-a-box approach are usually individual assignments. The latter may lead to students missing the feeling of shared accomplishment and collaboration. We maintain that implementing cooperative learning in the engineering labs may improve students' learning through experiencing trials and errors with their team members. Additionally, virtual teamwork replicates the way engineering industry and commerce function every day worldwide [22]. Reports suggest that 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 [21], [23].

In the five EE courses included into this study, we have formed virtual teams typically consisting of three students. The assignments were designed such that the individual tasks could be distributed as equally as possible among the team members. Description of individual responsibilities was required for the lab reports. It was expected that each team should accomplish their shared goals by working together, although each student should contribute to solving problems with his/her experience and understanding of the techniques. Students were also required to discuss the steps and procedures in finding solutions, potential alternatives, and limitations, much like a standard Senior Design Project.

Students were also required to use the online discussion board to contribute to the group chat on the lab procedures and results. In addition to the reports and discussion, team presentations were also mandatory. 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. Each team was given 10 to 15 minutes to present their work and answer questions.

C. Creating online learning community

Online lab activities should offer frequent opportunities for students to interact with their peers and instructors to facilitate active learning [2]. Blackboard Collaborate, discussion forums, and similar platforms can create a learning community for labs allowing communications that may lead to deeper understanding. Incorporating interactive course features, such as discussion boards or chat tools can create learning environments where students can feel their belonging to learning communities even though they may not have in-person interactions.

We were extensively using course discussion forum and Blackboard Collaborate tools to create a learning community. Instructors were frequently attending the discussion forum to initiate and moderate the discussion for each lab assignment. This instructor’s participation often encouraged students to engage more in the discussion. On the other hand, we have witnessed that students often helped each other on the experimental procedures and troubleshooting without any need for an instructor to intervene. Perhaps, this discussion forum somewhat resembles the lab chat that could occur during the traditional in-person labs.

Learners are also using collaborative tools to interact with their peers and class instructors, while seeking help with the O-E assignments. Such tools can enhance the sense of connectedness among peers and also the sense of belongingness. Additionally, our students have the opportunity to interact with EE students all levels and with other instructors through an additional group forum that includes our entire EE undergraduate cohort. We expect that improving the senses of connectedness and belongingness may also increase student retention [23], which will be assessed for the multiyear data.

D. Incorporating pre-lab simulations and pre-lab video demonstrations

Students often feel better prepared for laboratory assignments when these assignments include pre-lab activities [24]. They also indicate that pre-lab materials have positive effects on their learning [25]. We maintain that performing simulation resembling the actual lab experiments may provide students with knowledge and confidence by allowing them to perform similar (to the experimental) work in a risk-free environment where mistakes will not lead to catastrophic outcomes. Simulations may also provide the opportunity to correct such mistakes, while developing a better understanding of the underlying principles. Simulations may increase knowledge attainment and improve the student's confidence level [26].

On the other hand, pre-lab video demonstrations help alleviating the frustration that students may experience when working on the lab procedure [25]. Therefore, many online labs in this study were enhanced with pre-lab simulations and pre-lab video demonstrations. While most simulations provided a worry-free experience before practical experiments, some simulations were used as portions of the design process. Pre-lab videos for group labs often included discussions of specifications and general guidelines and tips for the experimental procedures.

3. Project Assessment

To assess the effectiveness of the four implemented strategies, we conducted experimental research by forming two lab groups in the five courses in this study: Circuits I, Electronics I, & II, Embedded System, and Signals & Systems. This was the second implementation of the strategies. The results of the first implementation were reported in [27].

This time, all courses have been offered both online and face-to-face. Students were randomly selected into either experimental group with the open-ended labs or control group with traditional lab assignments. Each group comprised of three to four students, and it remained the same throughout the semester in the given course. Therefore, the lab groups may include both online and face-to-face students; however, all group activities were restricted to the online format. A total of 128 students, who were enrolled in those five courses, were the study subject, and male students were the majority (88.3% male and 11.7% female).

a. Student Demographic Information

To invite student perceptions of their learning experience with the study intervention, we collected data through surveys and interviews. Approximately 59.38% students responded to surveys, and course instructors offered extra points for their participation. If a choice was given for the lab course formatting, almost half of the study participants (45%) indicated that they would like online setting, 37% of respondents indicated in-person (37%), and the rest (17%) indicated that they were not sure. Regarding their classification, the majority of the students were juniors and seniors (seniors 25%; juniors 62%; sophomores 11%; freshmen 0%). Most students (67%) indicated that they were employed at the time of the study, and 26% of them specified that their work was not academically relevant at all and more than half of them indicated that they were working more than twenty hours a week.

b. Student Learning Outcome Results

Table 1 illustrates the overall student learning performance evaluated with all learning assessment tools including quizzes, exams, discussions, and lab reports. The average lab scores are also reported. The performance results are illustrated separately for the Experimental groups (i.e., were all four strategies were implemented) and the Control group that did not have group assignments with the presentation requirements.

Table 1. Overall Student Learning Outcomes

Course Title	Average Score Across All Instruments		Lab Average Score	
	Exp. Gr.	Control Gr.	Exp. Gr.	Control Gr.
Circuits I	78.52 (N13, 2F)	86.84 (N12, 1F)	88.41	92.42
Electronics I	83.15 (N=11, 1F)	75.10 (N=9, 0F)	96.97	93.57
Electronics II	78.5 (N=15, 1F)	73.54 (N=13, 3F)	93.79	82.55
Embedded Systems	75.88 (N=12, 1F)	61.70 (N=14, 1F)	97.34	80.20
Signals and Systems	64.86 (N=15, 2F)	69.87 (N=14, 3F)	82.87	87.53
Total Number of Students	66 (7F)	62 (8F)	66	62

*N=total number of students; F=female students

When we examined the overall student learning outcome average scores in the five courses, the students in the experimental group outperformed in three courses: Electronics I, Electronics II, and Embedded Systems. This positive learning outcome was also observed in the average lab scores. The observed difference in the student learning outcome between the experimental group and control group can be perhaps explained by the student classification and the complexity of concepts. Circuit I and Signals and Systems typically cover theoretical concepts that are more fundamental and, perhaps, introductory in nature. Circuit I was taken by sophomores and the rest of the courses were taken by juniors. Electronics I, II, and Embedded Systems courses involve both complex concepts and hands-on applications that align well with active learning methods such as open-ended labs and online teamwork. These courses emphasize more problem-solving abilities that require pluralistic thinking and solutions, making the study intervention of active learning strategies particularly beneficial for students to understand course concepts in courses where complex concepts are required.

Further, what is noteworthy in our findings is that when assessing the student performance on the questions addressing more advance concepts, the experimental group participants show higher scores with the open-ended lab approaches in all five courses, as shown in Table 2. This learning outcome came from the summative learning assessment data, and the corresponding questions for the analysis were from the tests administered towards the end of each semester. This observation is also consistent with the first-year research findings [27]. When we compared these learning outcomes from the first-year implementation of the open-ended design [27], we noticed that average lab scores showed a similar pattern of having higher scores with open-ended lab approaches, and the overall learning outcome results are higher with the more improved open-ended lab approaches during this time.

Table 2. Student Performance with Advanced Concepts

Course Title	**Exp. Group**	**Control Gr.**	**Key Concepts**
Circuits I	73.8	60.1	Thevenin & Norton
	60.7	53.2	AC Nodal Analysis
Electronics I	72.73	33.34	Amplifier Design
	94.35	81.99	BJT DC Analysis
	88.18	77.78	MOS AC Analysis
Electronics II	99.78	87.69	Feedback and Stability
	86.32	84.21	Op-Amp Multistage
	93.33	76.92	Amplifier Freq. Response
Embedded Systems	75.00	53.33	Assembly Register Shifts
	91.67	80.00	Assembly Register Shifts
	66.67	53.33	Assembly PSR Flags
Signals and Systems	58.33	40.00	DS Fundamental Frequency
	83.33	80.00	Characterizing Discrete Signals
Grand Average	***80.32***	***66.30***	

In addition to the analysis of learning outcomes, we have observed that the 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:

> “Working in this group has improved my communication skills, and enhanced efficiency in task completion. It makes it easier on everyone who participates since it keeps one person from doing all the work” – team lab report Electronics I.

> “Working as a group allowed partners to educate each other on the material a bit better. Helping one another allowed us to solve issues with simulation errors to breadboard circuits when something was not working properly” – team lab report Electronics II.

While most student comments address the group activities, the following report is on the open-endedness of the assignment:

> “… The (lab) procedure was very clear on what the objectives were. We liked the flexibility that it gave us to choose any number, within certain parameters of course, that was a nice touch to allow our imagination to grow” – Tem lab report Embedded Systems

Students also have identified challenges they had to overcome to successfully complete the assignments.

> “Working in a group was rather challenging this semester because we had to overcome many obstacles such as not having a third partner, having to run other labs for different classes, and trying to make time for meeting up. It had a few pros like getting different perspectives and approaches to certain situations and finding out how to solve our problems. Due to the fact that we did not have a third partner, we did struggle more than other groups to complete, since they had one more team member to contribute, but we were able to turn it on time” – Team lab report Electronics I.

Based on the experimental group lab reports, time management and group dynamics were two most frequently reported challenges. Students indicated that finding the time when all group members could work on lab experiments, reports, and presentations was the main issue, since the majority of students were working, and some had family issues to attend. Challenges with the group dynamics were attributed to group members having varying levels of content knowledge preparedness, their willingness to participate, being individually and collaboratively accountable for contributing to the solution process.

Despite the reported challenges with the teamwork, the vast majority of students (69.23%) in the survey indicated working with classmates on class project helped them learn.

Moreover, students appear to form learning communities and recognize the benefits of working together by dealing with faced challenges as can be seen a student comment below.

> "Working in a group helped members understand the material better. If a person did not understand certain material, students had the opportunity to ask other members. If no member understood the question being asked, then all students would research the material online and work together to find the solution. Working as a group allowed for students to gain knowledge on different aspects of the material. Working together did help learn better"

4. Conclusions and Future Work

Students who learned in the open-ended laboratory in both online and face-to-face delivery modes showed generally more positive learning outcomes than their counterparts in the traditional laboratory setting. It is noteworthy that summative learning outcomes are noticeably higher for the students in the open-ended laboratory when we further examined student learning outcomes with advanced course concepts in all five courses. Regarding this consistently positive learning outcomes, the course instructors surmised that perhaps the collaborative nature of the groupwork helped students tackle more advanced concepts better than in the traditional lab setting. As can be seen from the study findings, students also see the benefit of working together and the open-ended laboratory setting can enable them to get into the pluralistic mindset in their problem-solving approaches. The caveat is that careful instructional planning for the lab works is crucial for the successful implementation of the open-ended laboratory including frequent monitoring of the student group works by course instructors and early interventions of lab groups if things do not work well as planned.

Student perceptions regarding the laboratory settings, however, were almost evenly mixed. Some students reported positive learning experiences with the open-ended lab settings through frequent interactions with their classmates through group projects, class discussions and presentations, whereas some students reported many challenges with the open-ended approach mainly due to time management and group dynamics. These mixed views from the students seem to be associated with the varying levels of individual learning preparedness, the expectations, and goals for their learning. For example, through surveys and interviews, many students indicated that working with team members was challenging because at times workload did not seem to be equally distributed and some of them preferred traditional lab format where they could simply find a solution without much exploring alternative solutions with peers.

Acknowledging the challenge of conducting research to measure the impact of instructional intervention on student learning due to its confounding nature, we chose to conduct experimental research with student randomization in this study. Yet, challenges remain because there are many other factors that can affect student learning outcomes, such as varying levels of engagement, preparation, prior knowledge. While the current study focused primarily on evaluating the effectiveness of active lab learning strategies, we recognize the importance of considering other contributing factors in future research to provide a more comprehensive understanding of the observed differences in student performance. To address this, we will explore additional measures to control for these factors in future studies, ensuring a more robust assessment of the impact of lab setup on student learning outcomes. Additionally, we plan to continue improving the open-ended laboratory modules and their implementations based on student learning data and their feedback. 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 student learning.

Acknowledgment

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

References

[1] S. Appana, "A Review of Benefits and Limitations of Online Learning in the Context of the Student, the Instructor and the Tenured Faculty", *International Journal on E-Learning,* vol. 7, no. 1, pp. 5-22. Waynesville, NC USA: Association for the Advancement of Computing in Education (AACE), 2008.

[2] M. Goryll, T.J. Thornton, C. Wang, S.M. Phillips, D. and Allee, "Online Undergraduate Laboratories in Electrical Engineering", *2019 IEEE Frontiers in Education Conference (FIE)*, pp 1-4, 2019.

[3] Y. Astatke, C.J. Scott, K.A. Connor, J.O. Ladeji-Osias, “Online Delivery of Electrical Engineering Laboratory Courses”, *ASEE Conference*, 2012

[4] M. Perales, L. Pedraza, and P. Moreno-Ger, “Work-In-Progress: Improving Online Higher Education with Virtual and Remote Labs”, *2019 IEEE Global Engineering Education Conference* (EDUCON), pp. 1136-1139, 2019.

[5] C. Wijenayake, M. D'Souza, A. Khatamianfar, K. Bialkowski, M. Ros, and P. Sutton, “Managing Hands-on Electrical and Computer Engineering Labs during the COVID-19 Pandemic”, *2021 IEEE Intl. Conf. on Engineering, Technology & Education (TALE)*, pp. 1051-1056, 2021.

[6] L.D. Feisel, and A.J. Rosa, “The role of the laboratory in undergraduate engineering education”, *Journal of Engineering Education*, vol. 94, no. 1, pp. 121-130, 2005.

[7] A. Rubaai, J.H. Johnson, and D. Cobbinah, ”The New Motors and Controls Laboratory at Howard University”, *Proceedings of 2005 ASEE Annual*, 2005.

[8] R.L. Clark, G.H. Flowers, P. Doolittle, K. Meehan, and R.W. Hendricks, “Work in Progress - Transitioning Lab-in-a-Box (LiaB) to the Community College Setting”, *IEEE Frontiers in Education*, San Antonio, TX, USA, 2009.

[9] H.R. Myler, “Value Added Engineering Education”, *2006 ASEE Gulf-southwest Annual Conference*, 2006.

[10] S.S. Holland, C.J. Prust, and R.W. Kelnhofer, “Effective Utilization of the Analog Discovery Board Across Upper-Division Electrical Engineering Courses”, *ASEE's 123rd Annual Conference and Exposition*, 2016.

[11] E. Van Hunnik, “Online college laboratory courses: can they be done and will they affect graduation and retention rates?” *Higher Learning Research Communications*, vol. 5, no.4. DOI: 10.18870/ hlrc.v5i4.289, 2015.

[12] N.J. Buch, and T.F. Wolff, “Classroom Teaching through Inquiry”, *J. Prof. Issues Eng. Ed. Prac.*, vol. 126, no.3, pp. 105, 2000.

[13] C. Gormally, P. Brickman, B. Hallar, and N. Armstrong, “Effects of Inquiry-based Learning on Students’ Science Literacy Skills and Confidence”, *Int. Jour. for the Scholarship of Teaching and Learning*, vol. 3, no. 2, 2009.

[14] A.H. Johnstone, and A. Al-Shuaili, “Learning in the laboratory; some thoughts from literature”, *Univ. Chem. Educ.*, vol. 5, pp. 42-51, 2001.

[15] A.-B. Hunter, S.L. Laursen, and E. Seymour, "Becoming a scientist: the role of undergraduate research in students' cognitive, personal and professional development", *Sci. Educ*., vol. 91, pp. 36-74, 2006.

[16] A.D. Pape, "A progressively open ended laboratory to promote active learning", *ASEE Annual Conference & Exposition. Chicago*, 2006.

[17] N.A. Rahman, N.T. Kofli, M.S. Takriff, S.R.S. Abdullah, "Comparative study between open ended laboratory and traditional laboratory", *IEEE Global Engineering Education Conference (EDUCON)*, 2011.

[18] K. Issen, "Open-Ended Design Problems", *Reflection in Engineering Education Workshop at University of Washington*, 2017.

[19] K.S. Cheruvelil, A.D. Palma-Dow, and K.A. Smith, "Strategies to promote effective student research teams in undergraduate biology labs", *The American Biology Teacher*, vol. 82, no 1, pp. 18-27. https://doi.org/10.1525/abt.2020.82.1.18, 2020.

[20] A.R. Emke, A.C. Butler, and D.P. Larsen, "Effects of team-based learning on short-term and long-term retention of factual knowledge", *Medical Teacher*, vol. 38, pp. 306-311, 2016.

[21] R. Ubell, "Virtual team learning", *Development and Learning in Organizations*, vol. 25, no. 1, 2011.

[22] S. Wuchty, B.F. Jones, and B. Uzzi, "The increasing dominance of teams in production of knowledge", *Science*, vol. 316, pp. 1036-1039, 2007.

[23] S.A. Joyner, M.B. Fuller, P.C. Holzweiss, S. Henderson, and R. Young, "The importance of student-instructor connections in graduate level online courses", *Journal of Online Learning and teaching*, vol. 10, no. 3, pp. 436-445, 2014.

[24] D.F. Jolley, S.R. Wilson, C. Kelso, G. O'Brien, C.E. Mason, "Analytical thinking, analytical action: using prelab video demonstrations and equizzes to improve undergraduate preparedness for analytical chemistry practical classes", *J. Chem. Educ.*, vol. 93, no. 11, pp. 1855-1862, 2016.

[25] B.P. Koehler, J.N. Orvis, "Internet-based prelaboratory tutorials and computer-based probes in general chemistry", *J. Chem. Educ*., vol. 80, no. 6, pp. 606, 2003.

[26] R.A. Blackburn, B. Villa-Marcos, D.P. Williams, "Preparing Students for Practical Sessions Using Laboratory Simulation Software". *J. Chem. Educ*., vol. 96, no. 1, pp. 153-158, 2019.

[27] J. Yoo, S. Sayil, G. Tcheslavski, "Board 208: Achieving Active Learning through Collaborative Online Lab Experiences". ASEE, 2023 Annual Conference & Exposition, Baltimore, MD, June 25-28, 2023.