The Future of Engineering Education
2024 Annual Conference & Exposition
Oregon Convention Center
Portland, OR . June 23 - 26, 2024
Paper ID #41611

Board 172: Engineering Electromagnetics Laboratory Development

Miss Narangoo Tumur, Southern Illinois University, Edwardsville

Narangoo Tumur is a senior electrical engineering student at Southern Illinois University Edwardsville. She is the president of IEEE student chapter at SIUE, and the member of ASEE.

Dr. Amardeep Kaur, Southern Illinois University, Edwardsville

Dr. Amardeep Kaur is an Associate Professor in the Department of Electrical and Computer Engineering at Southern Illinois University Edwardsville (SIUE). She received her Ph.D. in Electrical Engineering at Missouri University of Science and Technology, Rolla, MO in 2014. Her research interests are optical fiber sensors, harsh environment sensors, embeddable sensors, structural health monitoring, and engineering education. Dr. Kaur is a senior member of IEEE and also an active member of ASEE. She has held several leadership roles within the ASEE Midwest section and the ASEE Electrical and Computer Engineering Division.

Poster: Engineering Electromagnetics Laboratory Development

Narangoo Tumur and Amardeep Kaur
Department of Electrical and Computer Engineering, Southern Illinois University Edwardsville, Edwardsville, IL

Abstract

The learning enhancement brought on by hands-on experience is a well-established principle. For most engineering classes, laboratory (lab) experiments make an integral part of the curriculum. In engineering education, we place a lot of significance on student participation in the labs, but we seldom make students part of the curriculum and lab development. Through active involvement in lab development, students gain higher levels of learning and understanding. It is also well established that a good lab design involves open-ended design to provide sufficient challenge to students for them to achieve cognitive learning and practical skills. Our student-developed labs provide open-ended design opportunities to prompt questioning and higher-level evaluation of the knowledge acquired in class. The lab experiences discussed in this paper were designed by an undergraduate student who completed this work through the Undergraduate Research and Creative Activities program at the Southern Illinois University Edwardsville (SIUE). The paper presents the survey data gathered from students to understand their experiences and to incorporate continuous improvements in the lab experiences.

Introduction

Acquiring knowledge and comprehension stems from a diverse array of tools and methodologies. In the realm of engineering and technology studies, hands-on experience holds significant importance owing to the distinctive nature of the degree and curriculum. Hence, providing students with active hands-on experiences and involving students in design choices during the lab, coupled with their feedback fosters a more innovative and well-organized lab creation process [1].

The level of structure in laboratory courses may vary depending on the learning objectives of the course or curriculum and the academic level of students enrolled in the course, i.e., lower division vs upper division [2]. For example, a highly structured laboratory may be used to introduce students to laboratory analysis techniques and the use of laboratory equipment. At the other extreme is the unstructured laboratory which may be used at the senior level, requiring students to apply and synthesize skills to design and test a large-scale or multi-component system. For sophomores and juniors, blending various laboratory structures can enhance learning outcomes for both those engaged in crafting lab manuals and those replicating the lab experience to deepen understanding.

We designed the laboratory experiments that included some unstructured components in terms of design choices that students could make in each lab. Incorporating these design choices requires students to function at all levels of the cognitive domain namely, knowledge, comprehension, application, analysis, etc. [1][3]. The labs were designed by an undergraduate student who started the process while taking the course and continued to work through it afterward. This allowed us to bring student perspective not just to how we were presenting the labs but also to how students tend to use the lab manuals and other written or verbal instruction etc. We believe this led to clear instruction and student satisfaction with the overall experience.

Course Under Consideration

Engineering Electromagnetics is an undergraduate-level course at our university intended for Electrical Engineering students with Junior or Senior standing. The content primarily includes electromagnetic wave propagation, transmission line propagation, voltage and current waveforms with multi-boundary reflections, Smith chart analysis, and application of Maxwell's equations. The course is offered once a year with enrollment in recent years ranging between 30 and 40 students. Over the last three years, we have tried to transition the course from a traditional lecture course to a format with multi-point and multi-format content interaction for students. Online Kahoot! [4] quizzes with anonymous participation from students are used at the beginning of most classes to review the previous content and any misconceptions before introducing a new concept. Independent problem-solving and using online tools for live simulations [5] to provide visualization of concepts are the other learning aids that we have added. In addition to this, there was a need to include hands-on laboratory experience for a better understanding of the concepts and to promote effective learning on the student's part. Adding a full-laboratory course was not an option due to concerns about the increase in credit hours and resource availability. So short-form laboratory demonstrations were designed to be performed by students during class time to aid their learning.

Motivation

In engineering courses without lab experiences, students face challenges in understanding theoretical concepts, applying theoretical knowledge in real-life situations, and visualizing complex material from textbooks. These challenges become more prominent when the concepts do not directly relate to day-to-day applications. It is crucial to assist students in applying their knowledge to real-life scenarios. The Engineering Electromagnetics course lacked lab experiments, offering heavy theoretical content without practical applications of those concepts. Following were the motivations to incorporate lab experience into the class.

1. Incorporate more active learning opportunities.
2. Provide hands-on experience to students where they could visualize the concepts learned in class.
3. Provide real-world applications of theory learned in class with real-world limitations.
4. Prompt the students to think about the reasons behind any gaps between the theory learned in class and evidence of an application seen in the lab.
5. Provide multi-point interaction with fundamental concepts.
6. Conclude each lab experiment for all students during the lecture time (75 minutes).

Another motivation was to diversify the learning opportunities by integrating various learning styles into the conventional lecture format aimed to enhance student engagement with course material [6][7]. This diverse approach not only has the potential to spark greater interest but also encourages active participation through a variety of activities. Figure 1 shows the various tools that students use for the most important of the fundamental concepts. This multifaceted strategy not only promotes a deeper understanding of the subject matter but also nurtures a conducive atmosphere for continuous growth and mutual support, fostering a class environment that promotes engaging discussions and creating a more enriching educational experience.

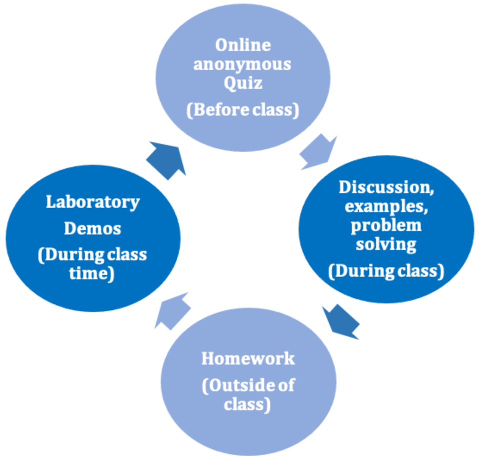

Figure 1: Course learning activities inside and outside of class.

Hands-on Laboratory Experience

Each of the labs included components of choices that students had to make and guided open-ended questions to promote discussion amongst group members and prompt questioning that helped better their understanding. Two sets of manuals were written - one for the students and one for the teaching assistant (TA) or instructors. Student manuals included basic steps to set up each experiment, information on what data they should collect or record, and questions that they needed to answer. In addition to this information, TA manuals also included troubleshooting information, additional components of engagement if a group finished early, correct data, and discussion pointers. The equipment and tools used for all of the labs were familiar to the students since they would have used the same or similar set of equipment for their Circuits labs. Long coaxial cables were the only new tools that they may not have used before.

Following is the list of laboratory demonstrations currently incorporated in the class. The labs were based on the concepts from the textbook [8] used for this class.

1. Difference between Lumped and Distributed Circuits: The objective of this lab was to demonstrate the need for different types of analysis for the two types of circuits. Students had a choice of creating different types of lumped circuits. A long coaxial cable was used as the distributed circuit. The practical aspect involves comparing the frequency responses of lumped and distributed circuits using capacitors and coaxial cables, examining oscilloscope readings at various frequencies, and discussing variations in behavior, especially at higher frequencies.
2. One-Way and Round-Trip Propagation Delay: The objective of this lab was to demonstrate measuring and visualizing propagation delay in reflection mode i.e., in the scenario that the coaxial cable’s load end is not accessible. Another objective was to demonstrate measurement instrument limitations and other practical considerations like impedance mismatches due to connectors etc. For example, for a certain length of the cable and at certain frequencies, round-trip propagation delay cannot be visualized. The students had a choice of testing frequencies and coaxial cable lengths for the short cables.

3. Time Domain Reflectometry (TDR): The objective of this lab was to demonstrate the use of TDR tools in the field by power engineers and technicians. The students observed the voltage pulse as it was sent down the cable and then reflected (or not) at the load end. By analyzing the voltage pulse, students were able to determine the reflection coefficient, type of load, length of the cable, etc. This demonstration also helped convey how the TDR would be used to find breakages or other faults in the line in an underground cable. The students had a choice to test different types of loads including open circuit, short circuit, under-matched, and over-matched loads.
4. Voltage Standing Wave Ratio (SWR): This lab focused on demonstrating the concepts of the standing wave ratio. The lab utilized an oscilloscope, waveform generators, and coaxial cables to simulate a SWR meter. The students were able to observe the standing wave patterns from the coaxial cable for various impedance match conditions. A video version of this experiment capturing multiple ratios was also created to be used as an instructional tool in class. The students had to evaluate an open-circuit load but had a choice to evaluate other types of loads including match, under-match, or over-match resistive loads.

Challenges

At the beginning of the process, the focus was on the lab design and the learning outcomes of the students. When we scheduled the first lab experience, there were some logistical challenges. Because the class does not have a dedicated lab course component and because of the limited number of lab spaces available, there was no guarantee that all students would be able to go through each lab during class time. There were enough students that could either start early or finish late around the class time and that made it possible for us to conduct the lab sessions during Spring 2023. For Spring 2024, we could request a class schedule where the lab spaces were available at least once a week several times a semester. This made it easier to schedule all students for their lab sessions at the same time in two lab spaces located next to each other. This meant that the teaching assistants and the instructor could be available for all students at the same time. This saved time in troubleshooting and engaging in meaningful discussions. We were fortunate that the schedule worked in Spring 2024 to allow us preparation time before each lab session. In the future, we plan to request scheduling so that we have an ample amount of preparation and troubleshooting time.

Student Feedback

Student surveys are an important tool to gather different types of feedback. The feedback could include student impressions about the content, facilities, quality of instruction, mode of instruction, etc. [9][10][11] Long-term use of surveys also provides data for continuous improvement [12] of activities and provides information about whether the changes result in a positive outcome. Our objective was to collect information that would help us improve the student learning experience in the future. We also wanted to know about students' likes and dislikes of the lab content. Some of the survey questions were structured similarly to a Likert Scale whereas others were intentionally left open-ended. Open-ended questions were included to provide students with feedback by way of written comments. These questions helped us identify the parts of the format and instruction that students liked and also provided us with the areas that we needed to improve on. The pre and post-survey responses helped us streamline the design from Spring 2023 to Spring 2024 to fit the available time duration for each lab session. We also wanted students to self-analyze their excitement level [13] to see whether most students generally came to the lab with a positive interest. This parameter was of interest since a perceived positive interest can lead to positive follow-through experiences [14].

Before each lab session, we administered pre-lab surveys to understand the level of excitement about the labs and their confidence level about concepts covered in each lab. After each lab, post-lab surveys were administered. Pre and post-lab surveys used in Spring 2023 are shown in Appendix A and the surveys used in Spring 2024 are shown in Appendix B. For the Spring 2024 surveys, we updated the pre-lab survey to include an additional question (question 3) asking, "Is lab experience crucial for enhancing your understanding and knowledge?" and also updated the post-lab survey to collect data that would help us improve the student experience and learning outcomes in the future [15]. These updates aimed to gain insight into students' perspectives on the importance of hands-on lab experiences in augmenting their comprehension and knowledge. Figure 2 shows the response to question 3 from the pre-lab survey conducted in one of the labs during Spring 2024. As seen, 89% of students agreed that having lab experiences is either crucial or important to enhancing their understanding and knowledge.

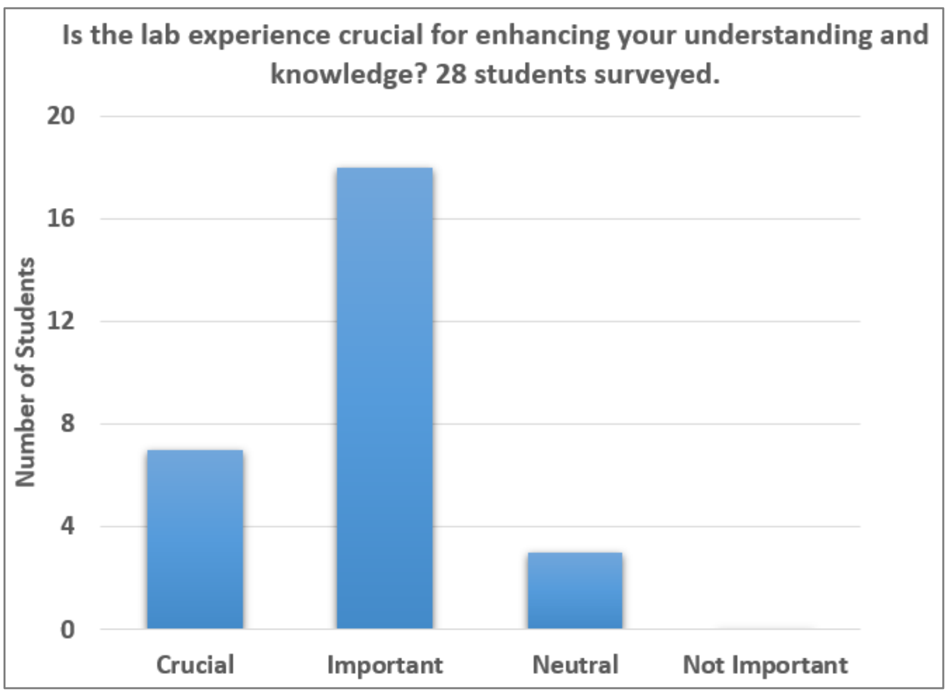

Figure 2: Responses to question 3 on the pre-lab survey of Spring 2024

Figure 3 shows a comparison of pre and post-lab survey questions about the confidence level of the students for the time domain reflectometry lab. Data indicates that more students felt a higher confidence level about their understanding of the concepts after the lab. We observed similar data from the other labs as well. Figure 4 shows a comparison of pre and post-lab survey questions about the confidence level of the students for the propagation (or time) delay reflectometry lab. Again, we observed that the confidence level amongst the students about their understanding of the concepts was higher after going through the lab than before.

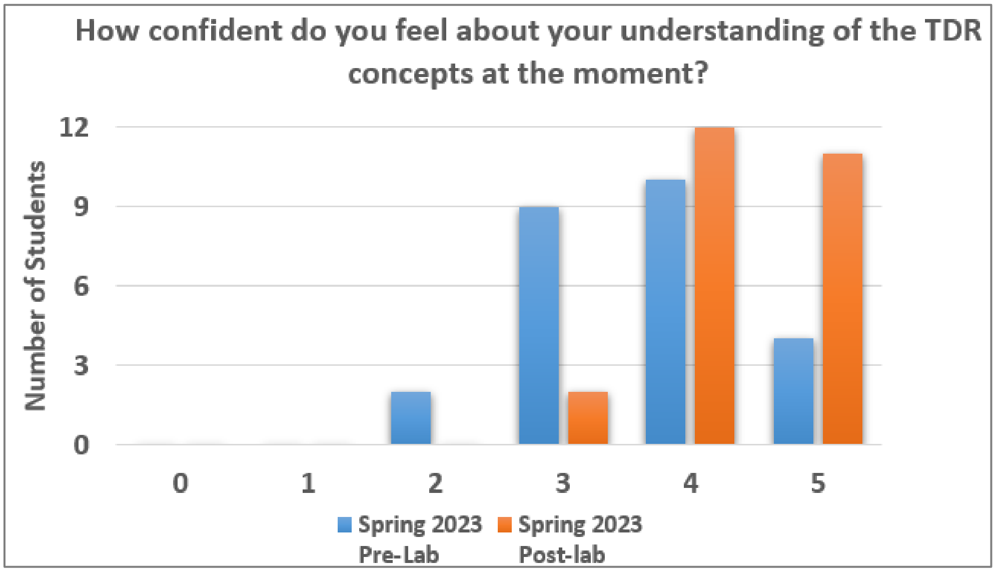

Figure 3: Spring 2023 Pre- and post-lab survey comparison on confidence level about the concepts covered in the TDR lab.

The survey data also indicated a considerable amount of enthusiasm in both the Spring of 2023 and 2024 amongst the students. In Spring 2023, 30% of students indicated that they were excited, and an impressive 70% indicated that they were very excited about the prospect of learning the concepts in the lab setting. Similarly in Spring 2024, over 90% of students expressed that they were either excited or very excited. Only around 10% of the surveyed individuals reported feeling neutral about the lab sessions. Figure 5 shows the comparison data for question 5 on the post-lab survey. This question asked whether students think that the lab exercises helped strengthen their understanding of the theoretical concepts learned in class. As seen, most students either agreed or strongly agreed with the statement.

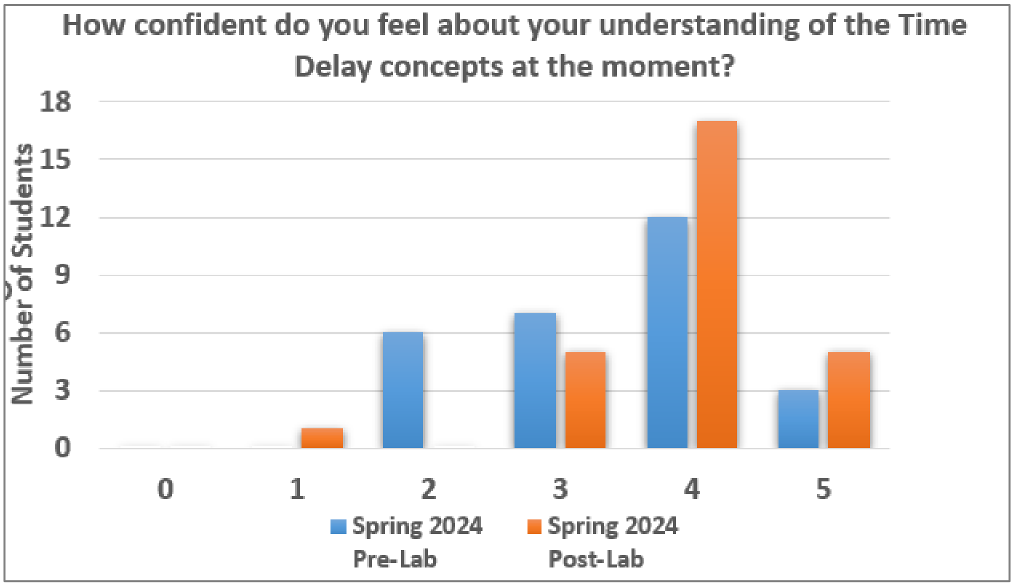

Figure 4: Spring 2024 Pre- and post-lab survey comparison on confidence level about the concepts covered in the time delay lab.

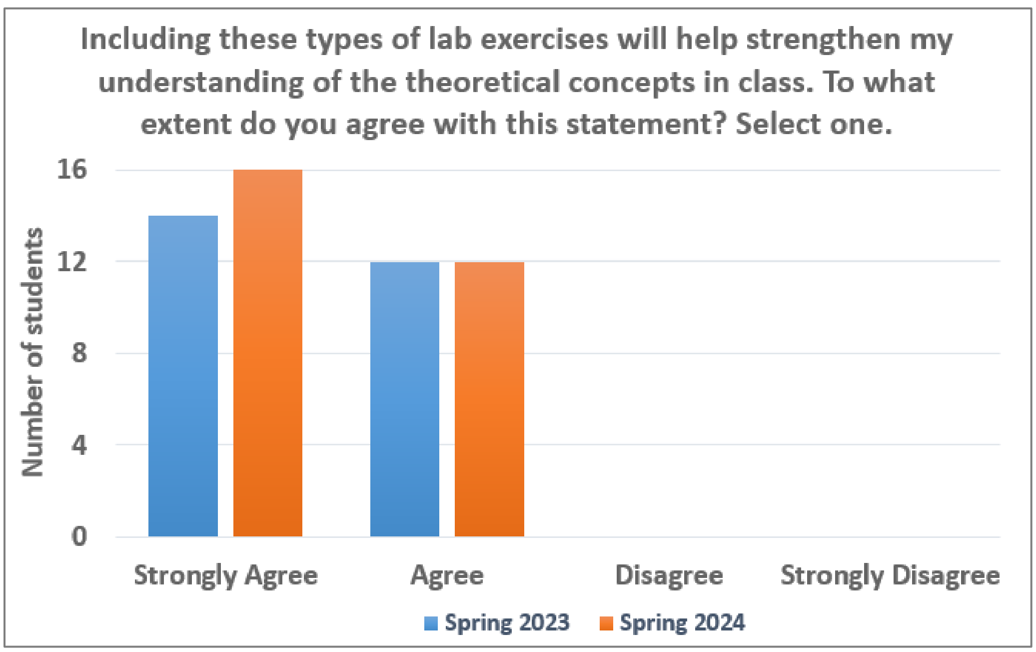

Figure 5: Post-lab survey question comparison for question 4 from the time delay lab from Spring 2023 and Spring 2024.

In the post-lab survey, we also asked students about possible future improvements, what they liked, and what they did not like about the lab experience. Most participants found the instructions clear and had no specific suggestions for improvement. They generally indicated that they liked the experience. In one of the labs, we had provided a redundant instruction to follow a step to connect an additional cable that was not possible. A few responses recommended removing that unnecessary instruction because it led to some confusion. One participant suggested including a diagram of the circuit connections to enhance clarity. Overall, while several participants expressed satisfaction, a few constructive suggestions were made to enhance clarity and address specific challenges in the instructions. We have incorporated these suggestions for future lab manuals. In Spring 2023, we received some feedback indicating that more time for lab work and refining the lab instructions for clarity would be helpful. After we updated the lab and the instructions on the lab manual, we did not receive similar comments in Spring 2024.

Figure 6: Keywords captured by one of the Spring 2024 surveys in response to the post-survey question about what the students liked about the lab.

From the survey data and in post-lab class discussions and other exchanges with students, students gave positive feedback about their lab experiences. Figure 6 shows some of the keywords captured from a Spring 2024 survey in response to a question about what the students liked about the lab. Many appreciated the visual representation of theoretical concepts, noting that seeing how class concepts applied to equipment enhanced their understanding. The alignment between predicted mathematical results and observed outcomes, especially regarding incident and reflection voltages on the oscilloscope, was well-received. The straightforward setup was liked by many, with some highlighting the significance of teamwork and the practical application of lecture concepts. The hands-on experience, real-life examples, and the opportunity to work with the oscilloscope were particularly commended, contributing to a better understanding of the material.

Conclusion

In conclusion, the introduction of brief laboratory experiences in the Engineering Electromagnetics course has proven to be a valuable addition, enhancing traditional lecture-based learning. These hands-on labs were designed to offer practical insights and reinforce theoretical concepts. The positive feedback from students, increased excitement levels, and improved confidence in understanding course topics highlight the success of this educational approach. The short-lab structure allowed us to bring the lab experience without adding a full lab course. There may be reservations amongst some faculty about losing the lecture time but in our experience, spending time on cementing the fundamentals led to a deeper understanding of later concepts. It was easier for the instructor to relate the content from the lab to the follow-up lectures and it was easier for the students to understand and build their understanding on what they had already learned. The instructor also observed an increase in class discussion and questions that the students asked. Students usually referred to their lab experience to ask pointed questions or if they thought that the new concept did not seem to support the evidence they had seen. In our experience, everybody gained by adding lab time at the expense of some lecture time.

Despite resource constraints and time limitations, the incorporation of short-form labs has effectively bridged the gap between theoretical knowledge and practical application. The student-designed experiments, active participation in lab development, and the collaborative learning environment have contributed to a more enriching educational experience. Moving forward, we will make continuous improvements to lab instructions and design based on student feedback. We will also continue to develop more labs to incorporate in this format and in a structure where the set-up can be easily brought to a classroom to aid learning. The interconnected course learning activities, as illustrated in Figure 1, emphasize the synergy between in-class and out-of-class components. By intertwining theoretical lectures, online quizzes, simulations, and hands-on labs, the course aims to provide a holistic and engaging learning experience for students.

For the student designer involved in designing the lab experiences and writing the manuals, this has proved to be a very rewarding technical and professional experience. The student designer explored the curriculum and generated innovative ideas for short-term laboratory experiments. This gave her insights into a structured way of doing research. Following thorough research on the subject and potential visualizations of these experiments, the student will formulate a demonstrative lab instruction. She also got trained in some new tools in the way of figuring out multiple possibilities and learned resource management since we had to design all experiments using the tools already available and within the class time. This experience has given her tools to approach learning and engaging with engineering in a constructive, structural, and meaningful way.

In summary, the incorporation of short-form labs in the Engineering Electromagnetics course has demonstrated significant benefits, enhancing student engagement, understanding, and confidence in applying theoretical concepts to real-world scenarios. The positive responses from students underscore the success of this approach, paving the way for further innovations in engineering education. By compressing lab experiences without compromising educational quality, students engaged in practical applications, fostering a more dynamic and participatory learning environment. This optimized the efficiency of the learning process and enriched the overall educational journey by providing a balance between theoretical knowledge and practical application.

References

[1] C. Saviz and K. Schulz, (2003, June), *Learning Design In Lab* Paper presented at 2003 Annual Conference, Nashville, Tennessee. 10.18260/1-2--12134.

[2] P. C. Wankat,, and P. S. Oreovicz, Teaching Engineering. McGraw-Hill, NY, 1993.

[3] Bloom, B. S., M. D. Engelhart, E. J. Furst, W. H. Hill, and D. R. Krathwohl. Taxonomy of Educational Objectives: The Classification of Educational Objectives. Handbook I: Cognitive Domain. MacKay, NY, 1956.

[4] "Kahoot!," (Accessed 2024). Available: https://kahoot.com/.

[5] "Falstad Applets," (Accessed 2024). Available: https://www.falstad.com/.

[6] A. Kaur and T. M. Swift, (2020, June), *Best 2019 Zone III Paper: Blended Learning: Electrical Circuits for Non-EE Students* Paper presented at 2020 ASEE Virtual Annual Conference Content Access, Virtual Online. 10.18260/1-2--34209.

[7] M. A. Vigeant, and M. J. Prince, & K. E. K. Nottis, and M. Koretsky, and E. C. Bent, & R. Cincotta, & K. A. MacDougall (2017, June), *Why not just run this as a demo? Differences in students' conceptual understanding after experiments or demonstrations* Paper presented at 2017 ASEE Annual Conference & Exposition, Columbus, Ohio. 10.18260/1-2--29129.

[8] U. Inan and A. Inan & R. Said, Engineering Electromagnetics and Waves. Pearson, 2014.

[9] S. Nikolic, C. Ritz, P. J. Vial, M. Ros and D. Stirling, "Decoding Student Satisfaction: How to Manage and Improve the Laboratory Experience," in IEEE Transactions on Education, vol. 58, no. 3, pp. 151-158, Aug. 2015, doi: 10.1109/TE.2014.2346474.

[10] D. Holtzhower & R. Mosier. (2019). A Survey of Undergraduate Students Utilizing an Interdisciplinary Laboratory Building. 10.18260/1-2--32004.

[11] S. Lal, et al. "The Effects of Remote Laboratory Implementation on Freshman Engineering Students' Experience." 2018 ASEE Annual Conference & Exposition Proceedings n. pag. Web.

[12] S.T. Ghanat et al. "Assessing the Influence of Lecture/Laboratory Instructor Pairings on Student Perception and Learning Outcomes." (2018).

[13] R. M. Ryan and E. L. Deci, Self-Determination Theory and the facilitation of intrinsic motivation, social development, and well-being, American Psychologist, 55, 2000, pp. 68–78.

[14] S. Sheppard & S. Gilmartin & H. Chen & K. Donaldson & G. Lichtenstein & Ö.Eris & M. Lande& G. Toye. (2010). Exploring the Engineering Student Experience: Findings from the Academic Pathways of People Learning Engineering Survey (APPLES).

[15] R.W. Williams & S. F. Rahmatalla (2021, June), *Use of Student Surveys to Improve Efficacy of Lab Experience and Guide Lab Development* Paper presented at 2010 North Midwest Section, Minnesota State University, Mankato, Minnesota. 10.18260/1-2-1128-36474.

Appendix A
Pre-Lab and Post-Lab Surveys used in Spring 2023

Pre-Lab Survey
Please fill out this survey *before* starting with the lab work.

1. How confident do you feel about your understanding of the TDR concepts at the moment? Rate your confidence level on a scale of 5 to 0. 5 being very confident and 0 being not at all confident.
2. Are you excited about seeing some real TDR signals using the lab equipment?
   Very excited *Excited* *Not excited*

Post Lab Survey
1. Did you learn something new from today's lab exercises?
2. Did these lab exercises help further your understanding of TDR concepts? Circle one.
   Most definitely *Definitely* *Somewhat* *Not at all*

3. How confident do you feel about your understanding of the TDR concepts now? Rate your confidence level on a scale of 5 to 0. 5 being very confident and 0 being not at all confident.
4. Including these types of lab exercises will help strengthen my understanding of the theoretical concepts learned in class. Circle one.
   Strongly agree *Agree* *Disagree* *Strongly disagree*

5. What did you like most about today's lab exercises?
6. What can we do to improve this experience in the future?

Appendix B
Pre-Lab and Post-Lab Surveys used in Spring 2024

Pre-Lab Survey

Please fill out this survey ***before*** starting with the lab work.

1. How confident do you feel about your understanding of <u>lumped and distributed circuit</u> concepts? Rate your confidence level on a scale of 5 to 0, 5 being very confident and 0 being not at all confident.

2. Are you excited about seeing some real visualization using the lab equipment? Circle one.
   Very excited *Excited* *Neutral* *Not excited*

3. Is the lab experience crucial for enhancing your understanding and knowledge? Circle one.
   Crucial *Important* *Neutral* *Not Important*

Post Lab Survey

Please fill out this survey ***after*** you have completed the lab work.

1. Did you learn something new from today's lab exercises?
2. Did the lab exercises help further understanding of <u>lumped and distributed circuits</u> concepts? Circle one.
   Most definitely *Definitely* *Somewhat* *Not at all*

3. How confident do you feel about your understanding of the concepts after the lab? Rate your confidence level on a scale of 5 to 0, 5 being very confident and 0 being not at all confident.
4. Including these types of lab exercises will help strengthen my understanding of the theoretical concepts in class. To what extent do you agree with this statement? Circle one.
   Strongly agree *Agree* *Disagree* *Strongly disagree.*

5. What did you like about this lab?
6. What did you not like about this lab?
7. Was this Lab demonstration worth your time?
8. What other Electromagnetics Concept demonstrations would you like to see?
9. Please rate the quality of instruction in the lab manual.
   Very Satisfied *Satisfied* *Neutral* *Not Satisfied*

10. How can we enhance the instructions provided in the LAB Manual?
11. Please let us know if there are other concerns you have. Expand on any of the answers you feel are necessary. We want these Labs to be as useful as possible, so your feedback is greatly appreciated.