WIP: Adventures in Electromagnetics: A Two-Year Exploration of Engaging, Hands-On Labs to Spark Curiosity and Deepen Understanding

Arthur C. Depoian II*, Son Vu*, and Colleen P. Bailey
Department of Electrical Engineering, University of North Texas, Denton, TX, USA

***Abstract*—This work in progress innovative practice paper represents the preliminary investigation of a two-year endeavor into the development of an introductory electromagnetics laboratory curriculum aimed at sparking the enthusiasm of undergraduate electrical engineering students. Departing from conventional lecture-based approaches, our endeavor immerses students in a realm of adventure labs and projects, placing active learning at the forefront. Through meticulously crafted prompts, students engage in a self-guided journey of critical thinking, fostering a deeper comprehension of theoretical concepts compared to passive methods. Our innovative approach breaks from tradition in several significant ways by contextualizing students' explorations within a historical framework in addition to recognizing and accommodating the diverse learning styles among our students.**

Over the past two years, the positive impact of this approach has been unequivocal. Students consistently express heightened enjoyment of the learning process, fueled by the hands-on, discovery-based nature of the labs. Emphasizing self-guided exploration and analysis has nurtured the development of critical thinking skills, empowering students to tackle complex problems with confidence. The incorporation of historical context, diverse communication channels, and a competitive element has resulted in a deeper understanding of the fundamental principles of electromagnetics.

***Index Terms*—Active Learning, Hands-on Learning, Critical Thinking, Engineering Education, Electromagnetics**

I. Introduction

The landscape of engineering education is constantly evolving, demanding innovative approaches to equip students with the necessary skills for success. While simulations and virtual experiments offer valuable tools for visualizing concepts [1], [2], a critical gap remains in fostering a deep understanding of fundamental electromagnetics principles. Traditional lecture-based curricula, typically focused on rote memorization and formula application, often fail to bridge the theory-practice divide, leaving students inadequately prepared to tackle real-world engineering challenges [3], [4], [5].

In this paper, a two-year investigation into the development of an innovative electromagnetics laboratory curriculum that prioritizes hands-on learning and active engagement is presented. Our proposed curriculum departs from the limitations of passive learning methodologies, where students act as receptacles for information disseminated through lectures and textbooks. Instead, we embrace a student-centered approach that emphasizes practical learning experiences, placing students at the center of the knowledge acquisition process [6], [7]. This shift in teaching style fosters deeper understanding by encouraging students to grapple with complex concepts through self-discovery and exploration.

Project-based learning serves as the cornerstone of our laboratory, mirroring successful implementations in other engineering courses [8], [9], [10]. Meticulously crafted projects, designed to resonate with real-world applications, provide a platform for students to translate theoretical knowledge into practical skills. Beyond reinforcing core electromagnetics principles, these projects cultivate essential competencies in design, analysis, problem-solving, and critical thinking. Students are not merely passive observers; they become active participants, constructing, testing, and analyzing devices that embody the principles explored in lectures. This hands-on approach develops a sense of ownership in the learning process, sparking curiosity and igniting a passion for electromagnetics.

Recognizing the diverse learning styles within the student body, our curriculum incorporates a multifaceted assessment approach that caters to individual strengths and preferences. While some laboratories culminate in the creation of formal IEEE-formatted reports, honing writing and technical communication skills, others prioritize the development of oral communication skills through presentations and group discussions. This flexible approach ensures that all students have the opportunity to demonstrate their understanding and showcase their achievements, promoting a more inclusive learning environment.

The curriculum also acknowledges the importance of historical context in fostering a deeper appreciation for electromagnetics. The course commences with a voyage through the history of the field, delving into the fascinating beginnings and evolution of this transformative technology [11], [12]. Understanding the historical context not only contextualizes the present, but also allows students to see electromagnetics as a dynamic discipline built upon the contributions of pioneering figures. By appreciating the historical narrative, students gain a deeper understanding of the "why" behind the equations and formulas, promoting a more intrinsic motivation for learning.

Our proposed approach, which incorporates project-based learning, historical context, and diverse assessment strategies, aims to bridge the theory-practice gap and ignite students'

*These authors contributed equally to this work.

enthusiasm for electromagnetics. By equipping students with critical thinking and problem-solving skills, coupled with a strong foundation in the fundamentals, this curriculum prepares them to thrive in the ever-evolving world of engineering.

II. Methodology and Framework

A. Course Structure

The laboratory component is designed as a progressive series of experiments, facilitating a cumulative learning experience throughout the semester, culminating in a challenging final project. The course commences with a historical exploration, grounding students in the field's captivating origins and evolution. This initial research-oriented lab serves a dual purpose: it introduces fundamental concepts through a historical lens while fostering technical communication skills via formal IEEE reports.

Acknowledging the plurality of learning modalities, the educational framework adopts a comprehensive evaluative strategy. Certain laboratory exercises conclude with the submission of written reports, whereas others prioritize verbal interactions through presentations and practical demonstrations within project-oriented activities. This strategy guarantees equitable success opportunities for all students, mitigating the constraints of written assessments in accurately evaluating knowledge amidst the proliferation of AI-generated content, and facilitating the adaptation of educational metrics to accommodate diverse learning demands.

A standardized curriculum structure guides student investigations across core topics like lumped components, transformers, transmission lines, and antennas. Each topic is reinforced by a hands-on project lab where students design and construct a device embodying the underlying principle. To solidify the connection between theory and practice, students explore the historical context and contemporary applications of each topic through investigations that may involve identifying relevant patents or commercial products. This multifaceted approach aims to ignite student enthusiasm for electromagnetics and equip them with critical thinking and problem-solving skills.

B. Project-based Learning

Project-based learning provides a foundation for the electromagnetics laboratory curriculum, creating a dynamic and engaging environment for students to master complex electromagnetic concepts. Through hands-on projects that mirror real-world applications, students gain a practical understanding of the theoretical principles.

The initial hands-on laboratory experiment focuses on inductors and transformers. Students delve into their characteristics and functionalities by constructing their own models. This exercise fosters practical experience in design and analysis of these essential electromagnetic components.

Following this, the speaker laboratory leverages the inductive field properties of a coil. When coupled with a magnet and attached to a paper cup, this configuration demonstrates the conversion of the inductive field into linear movement. Students are tasked with identifying a resonance curve using their own hearing, a signal generator, and various chosen waveforms.

The next lab explores the rotational electromotive action through a simple DC motor competition. Students are presented with an identical materials challenge: creating the fastest motor within a class-wide competition. This design challenge encourages students to apply their theoretical understanding to practical applications. The following week, the DC motor competition takes place. Instead of a formal report, the student groups present their motor designs and explain the underlying theory of operation alongside the rationale behind their design choices. The IEEE UNT Student Branch has come to support this competition, giving prizes to the winners and adding their own prize for best design and most creative design. This injection of healthy competition further enhances student engagement.

After this, the proximity sensor lab is designed to detect the presence of nearby objects without making physical contact. The challenge is to create and test a working capacitive sensor using conductive tape and sheets of paper to sense field changes, employing multiple objects of varying permeability and report on the findings.

At this point in the semester, the development of lumped models of transmission lines has been covered through previous labs and the corresponding lecture. Students are then tasked with the design and construction of bandpass filters using coaxial cables, and then measuring the response of the filter with a vector network analyzer (VNA). Through this session, students gain the ability to design and tune transmission line circuits for electronic applications.

Our final laboratory is a simple antenna of the students' design that must meet prescribed criteria for reception of a known set of signals being transmitted by the instructor. For this session, the formal report is replaced with an oral question and answer between the group and the instructor.

The pinnacle experience of the course is a student-selected final project with a focus on practical electromagnetic applications. Throughout the semester, students engage in ongoing discussions and brainstorming sessions to refine project ideas that align with this focus. Following the antennas laboratory, a dedicated engineering kick-off meeting facilitates further discussion and group formation for tackling the chosen engineering problem. Students then dedicate the remaining semester to project completion, with access to laboratory facilities, instructor guidance, and any additional resources they can secure. Examples of successfully completed projects include an antenna test bench and stereo plasma speakers.

III. Feedback and Observations

At the end of each semester, the university administers a course feedback survey to provide the data necessary for improving the curriculum. Over the past four semesters, the electromagnetics laboratory course has undergone continual updates, with each iteration reflecting valuable input from 54 of the 79 students. This process has significantly enhanced the course, addressing student needs while improving the overall

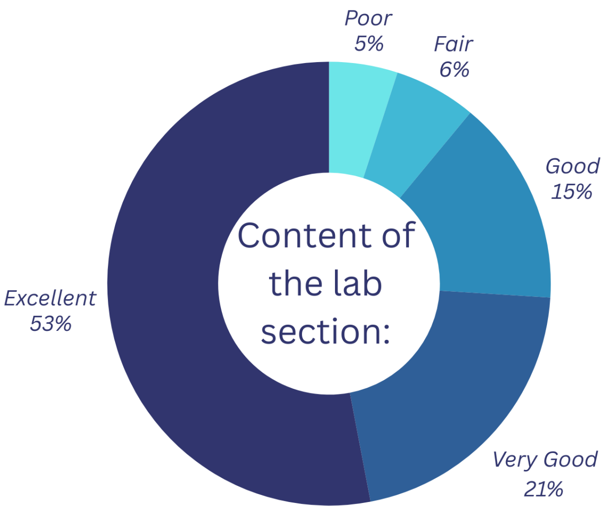

Fig. 1. Average content feedback over 3 semesters.

learning experience. Though not all changes were instant improvements, they each led to the current, most successful iteration. The overall content of the electromagnetics laboratory for all iterations is overwhelmingly positive, as shown in Fig. 1.

The first semester curriculum maintained the previously standard focus on software simulation, with the introduction of additional hands-on, project-based learning components. Student feedback of the simulation portions was strongly negative due to frequent software malfunctions and the need to be on the school's network for license access. In response, the second semester shifted more focus toward projects and reduced the emphasis on software simulations. Despite this adjustment, the course outcomes related to the remaining software lab sessions remained poor, leading to lower overall student satisfaction, as reflected in the course feedback surveys. Recognizing the need for further improvement, the third semester iteration completely removed the simulation components and concentrated on promoting a deeper understanding of the material through project-based learning. This approach was met with both higher approval from students and better overall performance, indicating a successful enhancement of the course structure.

In the most recent Spring 2024 semester, we leveraged the capabilities of Large Language Models (LLMs) to assist in crafting more exciting lab language for each of the projects, ensuring that the content remains engaging and relevant. This was extremely well received by the students and led to more creative reports and laboratory sessions overall from the perspective of the authors.

The goal of any course is to strike a balance between intellectual complexity and igniting enthusiasm for the subject. Even though the lab was deemed to be from comparable to much higher challenge than other courses (Fig. 2), students' overall satisfaction through survey was calculated to be 4.6/5, which is much higher than average.

Additional laboratory curriculum and learning environment survey question averages are shown in Fig. 3. Each of these metrics ranked very high, especially when 'excellent' and 'very good' answers are combined. A vast majority of respondents were engaged and further advancing their educational journey as a result of the lab sessions. These numbers agree with the enjoyment observed during lab sessions and continued engagement outside of class.

Even more beneficial than the numerical survey results are the open-ended responses that, without prompting, support the innovative design of the electromagnetics laboratory. The following short-response quotations demonstrate examples of the valuable feedback received.

Fall 2022: 'The lab was not simply following a lab guide and spitting out results. (The instructor) structured the lab to really stretch your thinking and promote problem-solving in the lab. The labs on the surface were simple but required applying what we learned in theory and applying it to practice. I wish the way that (the instructor) conducted labs was applied to more labs throughout the department. The labs made you think critically and do hands-on lab experiments rather than deriving equations and doing only simulations.'

Spring 2023: 'The hands on learning and also the in depth analysis that we had to do before we even began to do a hands on lab to make sure we knew what we were doing [contributed most to my learning].'

Fall 2023: 'Labs were extremely varied, and provided hands on examples of what we were learning in lectures. Felt like a real lab, rather than some which are just "build this circuit, then this one", we got to actually build components which held students attention spans well.'
'Compared to some of my other lab classes this is one that I found most interesting. The reason for that being is that it required a good amount of research on the students part and didn't provide all the answers to you up-front, which can be somewhat frustrating at times but understandably is

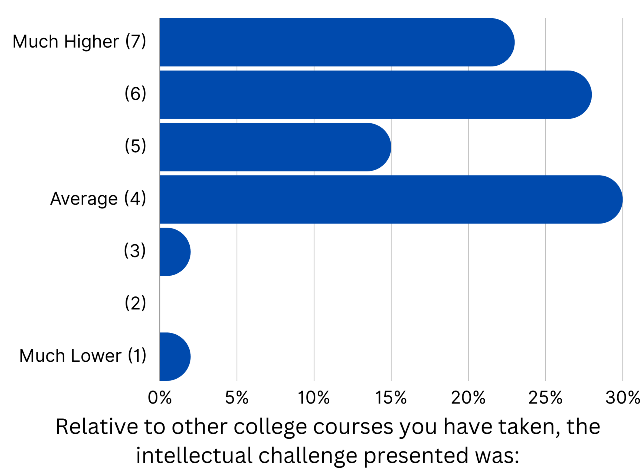

Fig. 2. Average intellectual challenge feedback over 3 semesters.

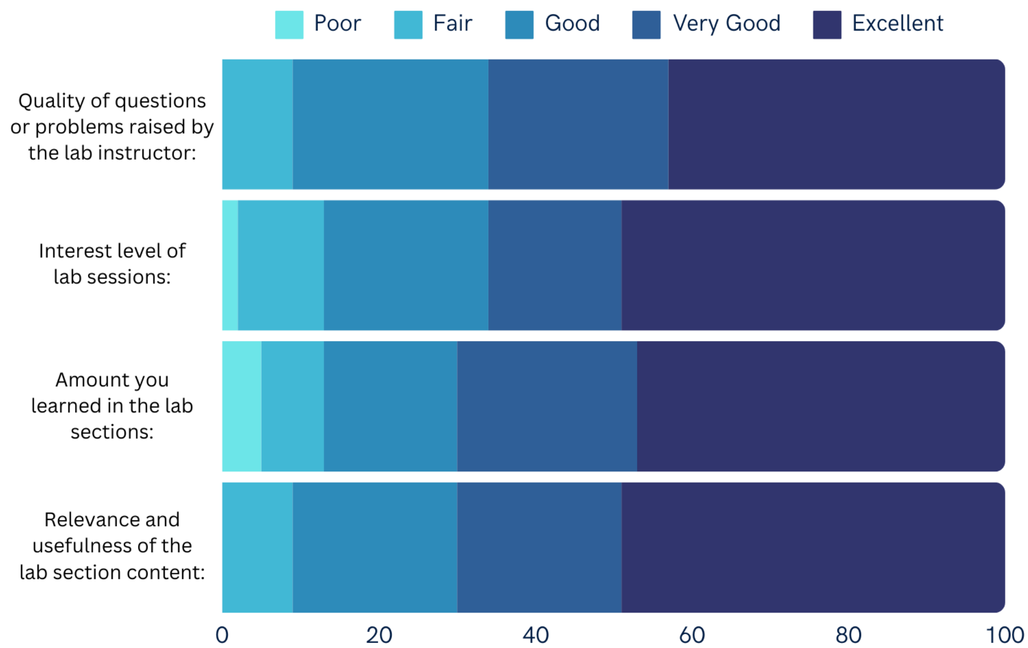

Fig. 3. Additional survey response, averaged over 3 semesters.

a necessary part of the learning process. The content taught in this class was seemingly on par with the material taught in the lecture portion of this class, and paced itself so that we would do a relevant lab after we covered the related material in class (most of the time).'

'Aspects that contributed most to my learning was the post lab reports. The instructor would ask challenging questions which you had to use knowledge previously known, learned during the lab, and after by doing research to answer.'

IV. Conclusion

This innovative practice work in progress paper presents a cutting-edge electromagnetics laboratory curriculum that prioritizes hands-on learning and interactive participation. The curriculum incorporates project-based learning, historical context, and diverse assessment strategies. A miniaturized engineering competition within the DC motor lab injects a spirited element of competition. Positive student feedback underscores the effectiveness of this approach in promoting critical thinking and practical skills. Future work will involve further refining the curriculum based on ongoing student feedback and assessment data.

References

[1] W.-J. Liao, R. Wu, T.-L. Wu, T. Ma, Y.-H. Pang, Z. Tsai, H.-H. Yu, K.-M. Tu, H.-C. Lin, and S. Peng, "Promoting effective education in electromagnetics: Taiwan's school of accessible and visualized electromagnetics formed [education corner]," *IEEE Antennas and Propagation Magazine*, vol. 58, pp. 99–129, 2016.

[2] L. Sevgi, "Teaching electromagnetics via virtual tools," in *2015 IEEE International Symposium on Antennas and Propagation USNC/URSI National Radio Science Meeting*, 2015, pp. 1021–1022.

[3] G. Tembrevilla, A. Phillion, and M. Zeadin, "Experiential learning in engineering education: A systematic literature review," *Journal of Engineering Education*, vol. 113, no. 1, pp. 195–218, 2024.

[4] A. Cavagnino, G. Pellegrino, A. Estebsari, E. Armando, and R. Bojoi, "A new laboratory for hands-on teaching of electrical engineering," 06 2018, pp. 883–889.

[5] V. Pulijala, A. R. Akula, and A. Syed, "A web-based virtual laboratory for electromagnetic theory," in *2013 IEEE Fifth International Conference on Technology for Education (t4e 2013)*, 2013, pp. 13–18.

[6] M. Popovic and D. Giannacopoulos, "Introducing student projects in introductory electromagnetics: what have we learned?" in *2006 IEEE Antennas and Propagation Society International Symposium*, 2006, pp. 1261–1264.

[7] H. Chowdhury, F. Alam, and I. Mustary, "Development of an innovative technique for teaching and learning of laboratory experiments for engineering courses," *Energy Procedia*, vol. 160, pp. 806–811, 2019, 2nd International Conference on Energy and Power, ICEP2018, 13–15 December 2018, Sydney, Australia.

[8] Y. Yu, Q. S. Cheng, and R. Barik, "Implementation of project-based learning in teaching an antenna and wave propagation course," in *2020 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)*, 2020, pp. 698–703.

[9] M. R. Varanasi, O. N. Garcia, P. Guturu, H. Deng, X. Li, and S. Fu, "Work in progress: An innovative electrical engineering program integrating project-oriented and lifelong learning pedagogies," in *Proceedings. Frontiers in Education. 36th Annual Conference*, 2006, pp. 7–8.

[10] R. J. Bowman, "Inspiring electrical engineering students through fully-engaged hands-on learning," in *2013 IEEE 56th International Midwest Symposium on Circuits and Systems (MWSCAS)*, 2013, pp. 574–577.

[11] W. Loendorf and T. Geyer, "Integrating historical technologies and their impact on society into today's engineering curriculum," in *2009 Annual Conference & Exposition*. Austin, Texas: ASEE Conferences, June 2009.

[12] K. C. D'Alessandro, M. K. Swenty, and W. N. Collins, "Integrating history into engineering curriculum," in *2014 ASEE Southeast Section Conference*. ASEE Conferences, 2014.