Enhancing the Learning Capabilities in Electromagnetic Field Theory Through Model Building

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***Abstract*—In the Electromagnetic Field Theory course, many concepts are difficult to visualize and, hence, to grasp. It might be difficult to understand the rectangular, cylindrical, and spherical coordinate systems and their transformations. To help students overcome the difficulty in grasping these concepts and their applications, different ways are being used by teachers and domain experts. This article delves into the efficacy of employing the 'learning by doing' pedagogical approach to address these challenges. It was observed that the technique helped to improve students' active participation in the activity beyond class hours. Impressively, around 30% of students took the initiative to construct three-dimensional models on selected topics. This approach has proven instrumental in fostering a deeper understanding of the orthogonal planes intrinsic to the three aforementioned coordinate systems. It also helped a few students to score in the evaluation because of their creativity. The 'learning by doing' approach and evaluation based on the activity was found to be a powerful tool for making students overcome the barriers to mastering intricate concepts in Electromagnetic Field Theory.**

***Keywords*— Electromagnetic Field Theory; learning by doing; learning outcome; pedagogy.**

ICTIEE* Track*: Pedagogy of Teaching and Learning
ICTIEE Sub-Track: Differentiated Instruction in meeting the need of every student.

I. INTRODUCTION

THE fundamental principles of mathematics and physics serve as the cornerstone upon which the concepts of various other subjects for undergraduate Electronics Engineering are built (Maciejewski et al., 2017). If compared with other branches of engineering, there is a need for instructional innovation and engagement of students in Electronics Engineering courses to feel confident and understand the relevance of the topics they learn (Maciejewski et al., 2017). Understanding students' learning styles is imperative before implementing teaching practices or developing an innovative teaching technique (Notaroš et al., 2019). Le Donne et al. identified various learning styles: sensing and intuitive, visual and auditory, inductive and deductive, active and reflective, and sequential and global. Using innovative practices, such as increasing cognitive activation and enhanced curricular activities, significantly improves learning outcomes (Le Donné et al., 2016). Nurutdinovaa et al. express the need for implementing teaching practices that would facilitate the development of the necessary skills and competencies (Nurutdinova et al., 2016). Nontraditional teaching techniques like gamification, case studies, self-directed learning, and the flipped classroom approach enhance student engagement and motivation, and it cultivate a deeper interest in learning (D\'\iaz-Ram\'\irez, 2020; Safapour et al., 2019). Hartikainen and Susanna examined and analyzed active learning methods within higher education in the field of engineering (Hartikainen et al., 2019). While there isn't a rigid definition of active learning, according to the authors, those who have incorporated this approach have consistently discovered its advantageous outcomes. It contributed to an enhancement in domain-specific knowledge. Kalainan et al. analyzed the effectiveness of innovative pedagogies such as collaborative, problem-based, and cooperative learning. The authors found those methods better than traditional teaching and suggested implementing small-group pedagogies for engineering and technology instructors (Kalaian et al., 2018). Maass et al. while reviewing the innovative teaching techniques for mathematics course, expressed that it is crucial to ascertain how novel teaching methods can be tailored to suit the specific local implementation conditions, all the while retaining their fundamental principles at the core (Maass et al., 2019) .

A course such as Electromagnetics is often viewed as a difficult subject by students. Teaching the core concepts of the subject linked with its applicability is challenging. This course is a compulsory course for Electronics and Telecommunication (E&TC) Engineering students and is an important course for the courses in their later semesters. In this article, an active learning activity named 'learning by doing' has been reviewed. This activity was conducted for the second-year engineering students of the E&TC branch for the course on Electromagnetic Field Theory (EMFT). For the course of EMFT, the challenge lies in

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students' ability to conceptualize point charges or charge distributions within various coordinate systems. Additionally, the complex task of vector transformation from one coordinate system to another proves challenging, rendering subsequent concepts even more difficult to comprehend. Consequently, their confidence lowers, dampening their overall enthusiasm for learning. The aim of the activity was to make them understand the concept of orthogonal planes in coordinate systems such as rectangular, cylindrical, and spherical and transformations from one coordinate system to another. The activity was a group activity and was evaluated.

The next section discusses the background of the activity through a brief literature review of similar activities. Details of the activity and responses of the students are discussed in the third section. The fourth section presents the impact analysis, and the last section concludes the paper.

II. Background

It has been noted by several researchers (Notaroš et al., 2019), (Beker et al., 1998), (Chetty et al., 2003) that students have an opinion that introductory electromagnetics is a difficult subject, and instructors also find it a difficult subject to teach. Indeed, while EMFT, or the theory of electromagnetic fields and waves, is a fundamental underpinning of technical education, it is often perceived as the most challenging and demanding course in the electrical engineering (EE) curriculum. The material is extremely abstract and mathematically rigorous, and students find it difficult to grasp, which is not unique to any particular school/department, country, or geographical region (Notaroš et al., 2019). The foundation of electrical engineering (EE) is built upon three fundamental pillars: signals and systems, electronic circuits, and electromagnetics (Chen et al., 2016). Numerous individuals dedicate their time and energy in developing computer programs, introducing simulation software, interactive resources, and more to enhance learning outcomes in this course and engage students for better learning experiences. (Beker et al., 1998) have used interactive tools for the subject of Electromagnetics. The authors used numerical tools and interactive visualization to demonstrate the practical application of theoretical knowledge. Their model was found relevant by students for solving assignments, however, many students did not try the software on their own. The software is not open source. (Chetty et al., 2003) have developed a module encompassing instructional tutorials, interactive simulations, and animations. Notably, the module emphasizes two key segments: the 'electric dipole' and 'experimental field mapping.' Authors found that as an educational tool, the module not only aids in grasping fundamental concepts but also cultivates a deeper appreciation for the practical applications of Electromagnetics theory. The module developed using JAVA, Perl and MATLAB was discussed in detail in that paper, however, its use for students has not been discussed by the authors. Computer modelling has been employed by Hoole and Ratnajeevan to help students transition smoothly from their freshman year, where programming is first introduced, to their senior year, where they are expected to apply programming skills (Hoole, 1993). Authors state that their model has a limitation that it does not provide suitable text. And hence teachers can explore and research it. Ulaby et al. introduced a new strategy incorporating a new textbook, an array of classroom demonstrations, and a laboratory component comprising nine practical exercises and a culminating team project (Ulaby & Hauck, 2000). The authors concluded that the laboratory's design, content, and significant role helped enhance the learning experience. Their strategy required a huge investment for setting up a lab. Notaros et al. implemented a computer-assisted MATLAB-based teaching technique for the Electromagnetics course (Notaroš et al., 2019). The authors concluded that the teaching technique engaged students in programming within electromagnetics and beyond these exercises, fostering enhanced learning motivation while cultivating a deeper understanding of the practical significance. However, to implement this technique, both, the teacher and student must be proficient in MATLAB programming.

The EMFT course includes coordinate systems, curl, divergence, charge, and current distributions. To illustrate the behavior of a point charge in 3-D space, the teacher must ensure students grasp the concept of the orthogonal nature of the rectangular coordinate system. Once this foundation is established, students are introduced to cylindrical and spherical coordinate systems. While comprehending a point charge within the rectangular coordinate system is relatively straightforward, visualizing the same within the other two coordinate systems is difficult. Problems that involve applying this concept can introduce intricacies, potentially leading students to feel a decline in their confidence and motivation to continue learning the course.

III. Methodology

In the fourth semester, the EMFT course was taught to the students of E&TC. For the activity 'learning by doing,' the methodology adopted is presented in Fig.1. As per the academic teaching guidelines, the evaluation plan for the course is discussed with students. During the discussion, they were provided with the details of the stage-wise conduction of the activity. After completing ten lectures, the list of topics for the activity was shared with them through Google Spreadsheet. The list included important topics on which a presentation, video, or model can be developed. The list of a few topics for this activity is shown in Table 1. Students were given time of 15 days to select a topic and form a group. There was a limit put on the number of students in a group. The model's limit was four students per group, and three students were allowed in a group for presentation or video. In the meantime, classroom teaching was continued. Students were given one month to work on their respective models/presentations/videos.

Presentations were scheduled during the regular lecture hour. Students were instructed to play the video prepared by the respective groups for topics starting from No. 4, as indicated in

Table 1, and presentations were given by the students on a few topics indicated in Table 1.

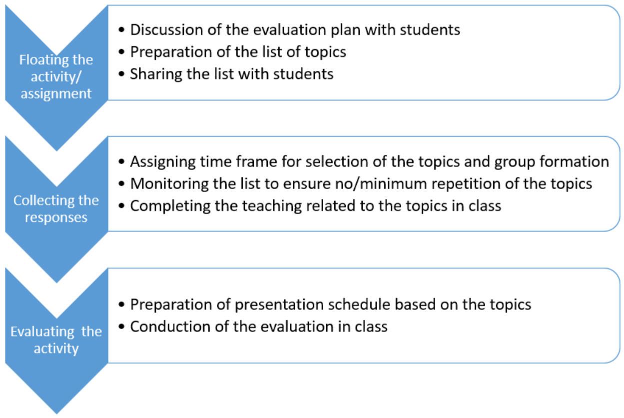

Fig. 1. Methodology for the "learning by doing" activity

The groups with models were asked to explain the thought behind the development of the model. Other students were encouraged to ask questions to the group presenting their work. The evaluation was conducted for this activity.

TABLE I
THE LIST OF A FEW TOPICS FOR THE 'LEARNING BY DOING' ACTIVITY

Sr. No.	Topic Name	Select the mode
1	Rectangular coordinate system	Model
2	Cylindrical coordinate System	Model
3	Spherical Coordinate System	Model
4	Rectangular coordinate system	Video
5	Cylindrical coordinate System	Video
6	Spherical Coordinate System	Video
7	Properties of Gradient of a scalar field	Video / PPT
8	Properties of divergence	Video /PPT
9	Properties of Curl	Video/PPT
10	Gauss's Law and Maxwell's equation	Video/PPT

IV. Implementation of the Activity

Students were asked to build models representing Cartesian /rectangular, cylindrical, and spherical coordinate systems. They were encouraged to show the differential surface areas in the three coordinate systems. The other option was given to them to make a video on the topic of their choice or create a presentation on the given topic. The time given for this activity was almost a month. After one month, students were asked to get the models in the class and demonstrate it as per the presentation schedule. Other students were asked to use the model to represent any point in that coordinate system. In the case of video making, they were asked to show the video in the class, and other students were encouraged to ask questions to them to understand more about that topic.

While a significant number of students were initially uncertain about selecting a topic for their projects and opted for creating videos, a handful of groups took the initiative to delve into model-making. These proactive groups successfully crafted models showcasing their creativity and comprehension of the subject matter and exhibited genuine enthusiasm. These models were then confidently presented during class sessions, where the presenting groups effectively addressed their classmates' inquiries. A few photographs of the models they created are shown in Fig. 2 to Fig. 6.

Fig. 2 depicts a basic model showcasing a sphere and the interrelation between Cartesian and Spherical Coordinates. In Fig. 3, a student demonstrated impressive creativity by constructing a model that illustrated the spherical coordinate system and impeccably visualized the transition from Spherical to Cartesian Coordinates. Additionally, the model elegantly portrayed the derivation of the Cylindrical Coordinate System from the Spherical Coordinate System. Including theta in the representation added a commendable dimension to the

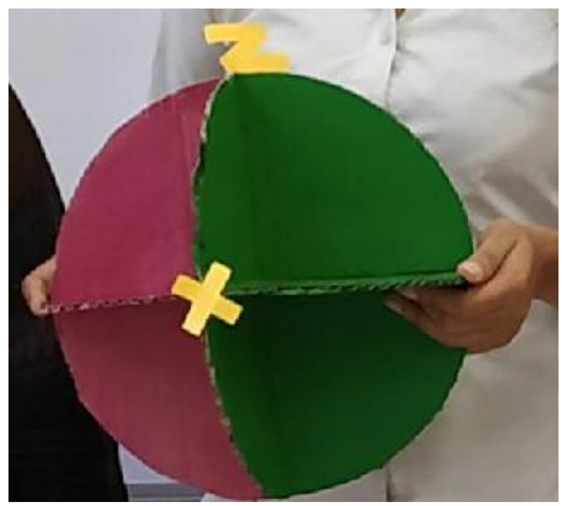

Fig. 2. Spherical Coordinate System in a Very Simple Form

Fig. 3. Spherical Coordinate System

Fig. 4. Differential Elements of Spherical Coordinate System

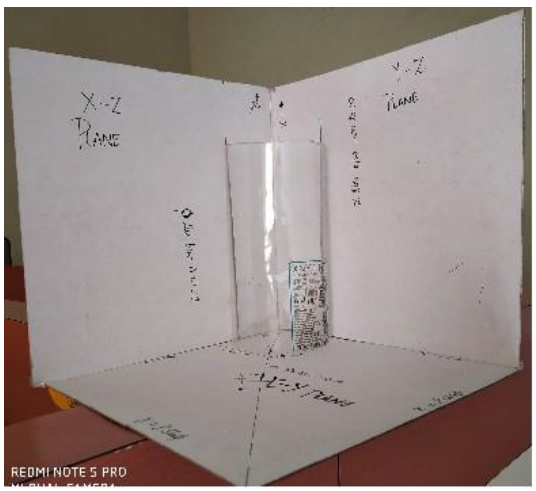

Fig. 5. Model Showing Relationship Between Cartesian and Cylindrical Coordinate System

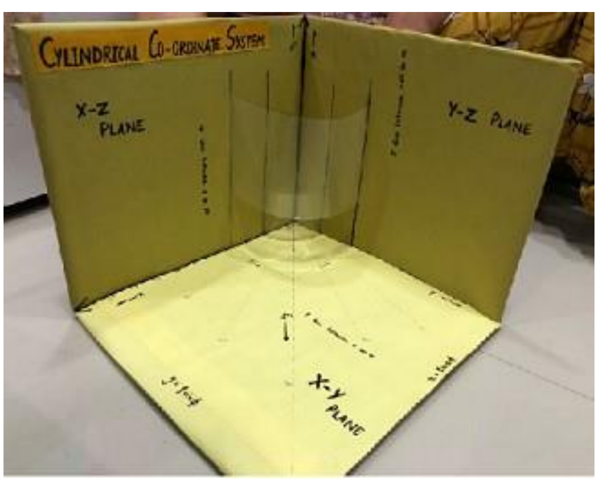

Fig. 6. Model Showing Relationship Between Cartesian and Cylindrical Coordinate System and Showing How Diameter and Height of Cylinder Changes

visualization. The excellence of this model didn't go unnoticed, as it garnered praise from fellow students. Its effectiveness in aiding the visualization of point charges within the spherical coordinate system was particularly appreciated. Furthermore, some students took inspiration from reference materials in Electromagnetics to devise another model, showcased in Fig. 4. This model skilfully captured the intricacies of differential elements within a spherical coordinate system.

Creating a visual representation of these differential elements is complex, but the students' resourcefulness and creativity were evident. The clever use of distinct colors to highlight various planes and the strategic placement of coordinates to elucidate the derivation of a differential element within the spherical coordinate system was undeniably impressive and captured the attention of all who viewed it.

One team devised a model elucidating the Cylindrical Coordinate System. Their representation was so intuitive that it facilitated effortless conversions between the Cylindrical and Cartesian coordinate systems. The model conspicuously exhibited the three defining planes, each labeled with its corresponding axes' bounds. To represent the cylindrical aspect, a transparent plastic bottle was ingeniously used (as depicted in Fig. 5).

In a similar vein, another group enhanced the Cylindrical Coordinate System model by incorporating an additional feature. This feature entailed a demonstration of how alterations in the height and radius of a cylinder manifest. The result is an exemplary illustration of the cylindrical coordinate system, impeccably demonstrated in Fig. 6.

The other groups presented their videos and presentation slides in class. Some videos combined animations of any coordinate system of the three and transformations of the same to other coordinate systems. Presentations were made by referring to the textbooks, reference books, and websites. The models and a few videos were the most effective.

V. Impact Analysis

The effectiveness of any teaching approach becomes apparent when contrasted with more traditional methods. The effectiveness of 'learning by doing' was examined within this context. This strategy was evaluated with other conventional assessment methods like unit tests and assignments. The outcomes of these assessments were subjected to two types of comparison: quantitative and qualitative.

Quantitative comparison was carried out by analyzing the scores achieved by students in four distinct assessments: assignments, the 'learning by doing' activity, class test, and unit test. While these assessments carried different maximum marks, they were normalized to a scale of 10 for the purpose of comparison. This normalization allowed for a meaningful quantitative analysis of student performance across these different evaluation components.

Fig. 7 shows the graph of students' scores in the four assessments. The scores are divided into five categories: students those were absent or scored below 40%, 40% to 50%, 51% to 70%, 71% to 80%, and 80% and above.

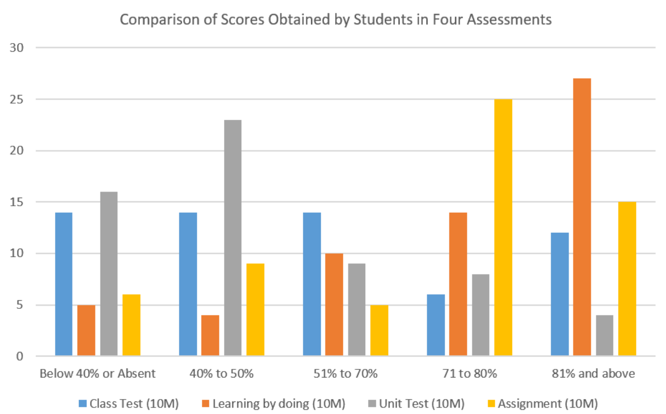

Fig. 7. Comparison of scores obtained by students in four evaluation components

The graph illustrates that more students participated in the activity, and a greater proportion of students achieved scores above 70% in this particular task. Students performed poorly in both tests, and scores were below 70% for the maximum number of students. The performance in "Assignment " segment closely mirrored that of the 'learning by doing' approach, particularly when scores were within the 70% range.

The further statistics such as mean, mode, median and standard deviation is shown in Table II. This is on the scores achieved by students in the four assessment categories.

TABLE II
THE STATISTICS OF THE SCORES ACHIEVED BY STUDENTS IN FOUR ASSESSMENT CATEGORIES

	Class Test	Learning by Doing	Unit Test	Assignment
Mean	5.81	7.32	4.47	6.89
Mode	8.5	10	8	8
Median	5.50	8.00	4.50	8.00
Standard Deviation	2.18	1.69	2.39	2.21

Analysis of Variance (ANOVA) was performed on the scores obtained by students in each assessment category. The ANOVA result showed the hypothesis that there is no difference between the components is rejected. Hence the pedagogy of learning by doing is more effective as indicated in the graph. The number of students scoring 81% and above are more as compared to other components.

Feedback was taken from students to understand the usefulness of this activity and to perform qualitative analysis. The questions posed to them were:

1. Do the 'learning by doing' activity make the subject interesting?
2. Do you find the 'learning by doing' activity helpful in visualizing charge distributions in different coordinate systems?
3. Do you have to explore topics on your own for this activity?
4. Do you think the evaluation based on 'learning by doing' helped to improve your score?
5. Do you find working in a group for this activity beneficial?

The response to the feedback form was received from 85% students. The percentage of positive responses is shown in Fig.8.

Observations revealed that the activity was crucial in facilitating students' comprehension of challenging concepts through hands-on engagement. Furthermore, students demonstrated genuine enthusiasm and engagement with the activity, as it provided them with a platform to showcase their creativity. The active participation of students in the task was a noteworthy aspect.

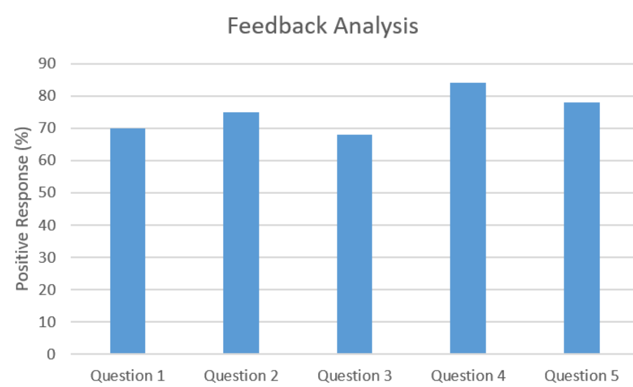

Fig. 7. Feedback analysis for the learning by doing activity

CONCLUSION

This study evaluated the effectiveness of the 'learning by doing' pedagogy in the Electromagnetic Field Theory course context. During the study, students actively crafted models of coordinate systems, created videos, and delivered presentations on specific assigned topics. The outcomes indicated a notable enhancement in student engagement, subsequently leading to improved academic performance. Student feedback underscored their enjoyment of this activity, highlighting its instrumental role in enhancing their grasp of coordinate system concepts and other concepts related to the course. The feedback further illuminated that the activity contributed to higher scores and resonated with their preference for collaborative work in smaller groups. Adding some more topics in this activity will further improve the learning experience of students.

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