Inculcating Multidisciplinary Learning in Electrical Engineering Undergraduate Curriculum through Problem-Based Learning

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***Abstract*— Recently, the multidisciplinary engineering education has been growing rapidly reflecting current technological concern. Engineering graduates from cross domains like mechanical engineering, computer science and engineering, electronics engineering in current market are in great demand. The National Education Policy NEP-2020 supports learning from multidiscipline in developing curriculum which is integrated and flexible in various learning environments. The goal of the multidisciplinary approach is to produce new age engineers who can become changemakers in dynamically changing industry. One such industry emerging rapidly in recent decades is the Electric Vehicles (EV). Students in the third year of undergraduate engineering from multiple disciplines take up an open elective on Electric Vehicles (EV) as a part of their curriculum. Multidisciplinary learning is essential for engineering students since sustainable transportation with EVs necessitates a thorough understanding across several engineering domains. Students from different educational backgrounds frequently encounter difficulties due to the lack of disciplinary knowledge as the EV course is multidisciplinary. To address all these issues, the study in this paper proposes a conceptual framework for designing an Electric Vehicle (EV) course by integrating with Problem-Based Learning (PBL). To provide the students with the multidisciplinary learning experience we present this paper as a case-study on how the engineering courses can be integrated with PBL.**

***Keywords* — Problem-Based Learning (PBL), Electric Vehicles, Multidisciplinary Learning, Collaborative Learning, Learning Theories**

I. INTRODUCTION

Research in engineering education highlights the significance of multidisciplinary curriculum inculcation in undergraduate courses (Litzinger, 2011). The National-Educational-Policy emphasizes integrated, flexible & integrated curriculums to prepare students for the dynamically changing industry (Kandakatla et al., 2024). Integration of concepts from multiple engineering disciplines such as data science engineering, computer science engineering, electronics and communication engineering; mechanical engineering enable students to develop innovative solutions to industry-related challenges (Treagust & Mills, 2003). Electric vehicle (EV) technology have been outperforming in the global industry in recent decade. Because of sustainable transportation, engineers from multiple disciplines need to fully understand the subtleties of Electric Vehicles (EVs). In this regard, the knowledge of EVs has been an immediate focus as it needs thorough understanding across multiple disciplines. To develop a solution to an electric vehicle problem, the fundamental concepts of mechanical, electrical, electronic, and computer science should be thoroughly practiced (Ehsani et al., 2018). This multidisciplinary nature of electric vehicles (EVs) brings challenges in terms of collaborative work, the common baseline of fundamental knowledge, and also bridging the gap between theory and practice.

Multidisciplinary can be classified into various degrees as per their intersections. In shallow multidisciplinary, the intersection between the disciplines is limited. It means students or researchers from two disciplines start learning about each other's disciplinary artifacts in order to identify how they fit together (McComb, 2021). Researchers (Van Barneveld and Strobel, 2009) mentioned that the students lacking in persistent motivation to learn till the end of the course is a major challenge. Inculcating multidisciplinary learning through Problem-Based Learning in an electrical engineering undergraduate curriculum for electric vehicle course is presented as a framework in this study. This study helps engineering students to build problem-solving ability in innovativeness by integrating knowledge from diverse backgrounds (Asundi et al., 2021).

II. BACKGROUND STUDY

Dym (2005) mentioned that the gap between the classroom learning and industry experience can be bridged by integrating Problem-Based Learning into the course. Engineering students not only collaborate using these approaches but also gain deeper knowledge leading to abstract knowledge and generalization, so that they can apply the knowledge and skills in any context (Hmelo-Silver, 2004). The level of understanding of concepts from core subjects like mathematics, physics, and chemistry may vary from student to student. The disparities could be due to the student's past learning experience. This background educational experience affects the expertise and comprehension through the objective of the fundamental courses is to provide the same baseline for students. As per the literature the Problem-Based Learning (PBL), not only fills this knowledge gap but also encourages problem-solving and original thought processing (Amashi et al., 2021). These studies on Problem-Based Learning (PBL) exhibit the significance of PBL in multidisciplinary electric vehicle (EV) courses and achieving the intended learning outcomes.

This paper presents a conceptual framework for the integration of PBL into the Electric Vehicles, while being aware of the various challenges encountered by engineering faculty and students in multidisciplinary engineering courses (Koppikar et al., 2023) This course requires students from various knowledge domains such as electrical and electronics engineering, computer science engineering, and mechanical and civil engineering disciplines to solve problems related to the EV industry. Foundational workshops and collaborative peer learning are used to create a common baseline of knowledge (Johnson, Johnson & Smith, 1998). Multidisciplinary teams working in a collaborative environment to tackle case studies and projects is also a huge challenge.

The constructivist theory holds the fact that learners gain knowledge and understanding when interacting with the environment and through learning experiences. These theories align with Problem-Based Learning (PBL) which holds the fact that learners apply the knowledge from multiple disciplines to solve real-world problems. Problem-Based Learning (PBL) enables learning to happen when the students undergo these three steps: 1. What do they know, 2. What do they need to know, 3. How can they find out what they need to know (Elsaary et al., 2015). It is reflected in the cyclic process of formulation of hypotheses, developing and testing of solutions, and reflections in the Problem-Based Learning process (Savery, 2015).

According to Kolb's Experiential Learning Theory (ELT), knowledge is gained through experience. Kolb mentioned four phases of experience in his theory. They are concrete experience, reflective observation, abstract conceptualization, and active experimentation. The Problem-Based Learning (PBL) aligns with Kolb's experiential theory. In PBL, these phases are embodied by learners' practical problem solving - concrete experience, thinking abstractly about theories and solution-abstract conceptualization, reflecting on their learning experiences and results-reflective observation, and applying their solutions in real-world settings-active experimentation. This theory helps the learners to integrate theoretical knowledge from multiple disciplines into real-world issues in the multidisciplinary learning environment (Kolb & Kolb, 2017; Hmelo-Silver, 2004)

Collaborative learning signifies the importance of multidisciplinary learning as it enables concept sharing and building expertise among multiple engineering disciplines (Baligar et al., 2022). Through collaborative discussions and peer interactions, the students are exposed to inquiry-based learning which fosters the collaborative learning experience (Johnson & Johnson, 2009). The collaborative learning nature of Problem-Based Learning (PBL) complements the social learning theory where students construct knowledge through interactions in teams (Dolmans et al., 2005). According to Ali, many academic institutions using Problem-Based Learning (PBL) demonstrate its ability to develop students problem-solving and critical thinking skills (Ali et al., 2023). Few research studies also showed that PBL approach is used to teach ethics to assess the students ability to identify and resolve ethical dilemmas while working together on a problem (Koppikar et al., 2022). In the entire process, the students work together in building on one another’s talents to solve the problems. This multidisciplinary collaboration helps enable engineering students to get ready for the industry workforce (Borrego & Newswander, 2008). This usage of Problem-Based Learning (PBL) to address multidisciplinary challenges is developed for the electric vehicle (EV) course as a conceptual framework. The objective of this paper is to create and put into practice a supportive framework for students with multidisciplinary backgrounds that enable them to collaborate and bridge the knowledge gaps in an electric vehicle (EV) course.

III. CONTEXT OF STUDY

The Electric Vehicle open elective, which is commonly offered as 3-credit course in the 3rd year of engineering was picked to be redesigned using PBL as part of faculty development programs led by the Center for Engineering Education Development at KG Reddy College of Engineering and Technology (Tuti et al., 2016). Problem-Based Learning (PBL) when employed as a pedagogy bridges the gap between theory and practice and also allow students to engage effectively in the entire learning process. Students who select Electric Vehicles as an open elective are expected to submit a final project as a group. Students are therefore expected to form teams based on their strengths and weaknesses so they can effectively collaborate and submit the final project. The third-year EV course is a 3-credit introductory open elective with prerequisites as mentioned in Table 1.

TABLE 1
PRE-REQUISITES OF ELECTRIC VEHICLE (EV) OPEN ELECTIVE

Prerequisite Area	Topics
From Foundational Mathematics	Calculus (Differential and Integral), Linear Algebra, Differential equations
From Basic Physics Course	Mechanics, Electricity and Magnetism, Thermodynamics
Computer Science Students	Introduction to Programming, Data Structures & algorithms, Computer architecture
Mechanical Engineering Students	Statics and Dynamics, Strength of Materials, Fluid Mechanics, Heat Transfer
Civil Engineering Students	Structural Analysis, Introduction to Environmental Engineering, Basics of Transportation Engineering
Electronic Engineering Students	Circuit Analysis, Analog and Digital Electronics, Microprocessors and Microcontrollers
From Basic Electrical Engineering Course	Circuit Theory, Electrical Machines

The intended learning outcomes of the EV open elective are as follows:

CO1 - Demonstrate the ability to integrate the knowledge from various disciplines to develop a comprehensive knowledge of Electric Vehicles (EV) technologies.

CO2 - Analyze the working of essential parts of electric vehicles such as electric drive trains, battery management systems, and charging infrastructure through collaborative research and discussions.

CO3 - Design and implement a solution for semi and ill-structured problems related to the EV by working collaboratively in a multidisciplinary team setting.

CO4 - Reflect on the significance of sustainable engineering methods in the development of electric vehicle (EV) technologies.

The learning outcomes CO1, CO2 and CO3 are aligned with constructivist theory and the CO4 with experiential learning theory. They are pictorially represented in the Fig.1. Constructivist theory underpins Problem-Based Learning through collaborative learning, critical thinking and innovation and reflective practice.

IV. CONCEPTUAL FRAMEWORK FOR ELECTRIC VEHICLES COURSE

The conceptual framework for electric vehicles course is shown in the figure Fig.1. This framework is derived from the existing research (Tan, 2003 & Mohd-Yusof, 2014).

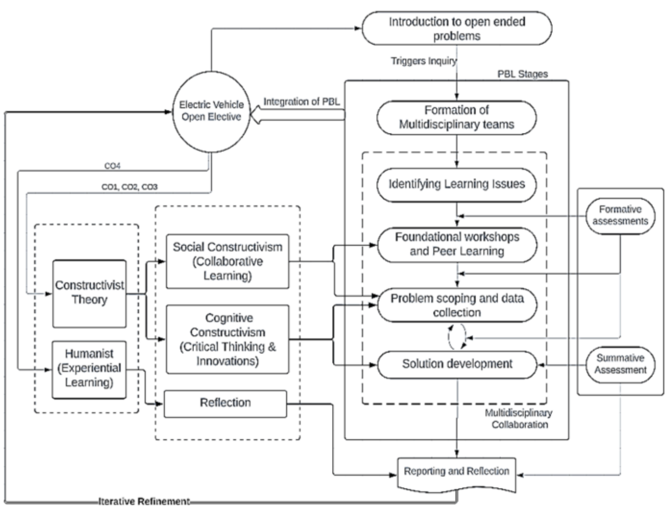

Fig. 1. Conceptual Framework EV course of Problem-Based Learning

The multidisciplinary learning approach integrated with Problem-Based Learning (PBL) is presented in the phases below

A. Course Design and Framework Development

The structure of the course is designed in the following way:

• Semi and ill-structured problem statements are introduced to the students enrolled into the electric vehicle (EV) course from various disciplines.

• Students enrolled in the course are organized into multidisciplinary teams consisting of a mix of technical expertise. These teams work on the initial analysis of the problem statements given and generate the learning issues. Learning issues are those conceptual gaps identified for the students where they need to gain to further proceed in problem solving process.

• Once the teams are formed foundational workshops are conducted which consist of the basic knowledge related to electric vehicle concepts. In these sessions, students are also made to have peer learning with in their multidisciplinary groups where they can share topics from their core domains related to EVs. This enables students to build upon each other's strengths and establishment of a common baseline. This peer learning and foundational workshops also address students' prior knowledge in making it more sound. This process encourages the students to recollect and apply their prior knowledge to various domains including electronics engineering, electrical engineering, mechanical and civil engineering and computer science engineering by supporting the knowledge construction process. Rather than just receiving the knowledge, the students can actively generate their comprehension by practicing the exercises and case studies within the groups.

B. *Implementation of the Course Projects*

• Post foundational workshops and peer learning the multidisciplinary teams start working on problem scoping and data collection process where they will gather relevant information by defining the parameters of the problem.

• Once the data is gathered and analyzed the students start working on developing the solutions to the open-ended problems combining the insights from various domains. In this phase, the students integrate the theoretical knowledge from multiple fields in the problem-solving process which in turn helps in facilitating abstract conceptualization. The development of innovative solutions needs iterative problem-solving by revisiting the data collection process and analysis. This iterative problem-solving approach helps students to gain mastery in conceptual knowledge of EV technology.

C. Data Collection and Analysis

Data collection methods like qualitative and quantitative are used in this process:

• To measure the student's level of confidence and problem-solving ability with multidisciplinary learning pre- and post-course surveys are conducted.

• To measure the technical expertise on EV concepts various metrics are used including formative assessments, project reports, etc., to gauge the performance of the students. Integration of multidisciplinary knowledge, developing innovative solutions to open-ended problems, and problem-solving abilities are the main evaluations done by designing rubrics with the above criteria.

• Student Reflections and Feedback: Focus groups, feedback meetings, and student reflections are the sources of qualitative data. This information shed light on the PBL approach's efficacy as well as the learning experiences of the students.

D. Evaluation of Outcomes

The following standards are applied for evaluating the results:

• Knowledge Integration: The degree to which students were able to effectively use their knowledge from several subject areas to address EV issues.

• Collaborative Skills: Students' capacity to function well in multidisciplinary teams will increase as they build the knowledge constructively. Students in the electric vehicle course collaborate in multidisciplinary teams within a group learning environment, utilizing social learning theory. In a multidisciplinary setting, this social learning component is essential because it fosters sharing of various viewpoints and methods, improving the overall educational process and advancing a better comprehension of challenging EV-related issues. Enhancement of student’s abilities to recognize, evaluate, and resolve complicated, real-world situations is known as "problem-solving abilities."

• Innovation: The fresh ideas and usefulness of the solutions that the student teams came up with.

The entire Problem-Based Learning process is evaluated by formative assessments at the end of each stage to check the level of learning for the parameters mentioned above. The overall objectives are evaluated using summative assessments at the end of the stage (Akor, 2020).

E. Reflection and Reporting

The multidisciplinary teams reflect and report on their educational experiences to present the findings and insights when the course comes to an end. Reflection gives the relation between the learning the problem-solving goals. Reflection is articulated in the form of a reflection journal at every stage of the learning process and submitted as a whole at the end of the problem-solving process. This helps the students to relate the current knowledge to pre-requisite knowledge as well as to enable them to understand how the problem-solving skills and learning process can be reapplied in future.

F. *Iterative Improvement*

The approach also featured an iterative improvement process that involved improving the course framework based on input from teachers and students. Based on this feedback, the issue statements, team formation techniques, and fundamental workshops are modified to improve the course's overall efficacy. The iterative process of developing solutions and receiving feedback help students refine their ideas and improve their understanding of EV technology. This iterative learning process is crucial in preparing students for the rapidly changing technological landscape.

Scaffolding is provided by the instructors throughout the framework. Guided support is given at the initial stages of PBL whereas the scaffolding is gradually faded out to support self-regulatory learning. This enables the engineering students of the EV open elective to construct their knowledge on their own and become lifelong learners. The assessments are carried out through the phases of PBL in the form of review for both internal and final gradings. Based on the assessments and surveys carried out by students and instructors the multidisciplinary EV open elective is iteratively refined in both the content and pedagogy.

V. RESULTS

The implementation of the proposed framework for the Electric Vehicle (EV) course, based on Problem-Based Learning (PBL), demonstrates significant improvements in multidisciplinary learning among undergraduate engineering students. The supportive framework presented in the study for inculcating multidisciplinary learning indicates the gaps in the current offering of the course. The framework will bridge the knowledge gap among students through structured collaboration opportunities with their peers from other disciplines. This framework also demonstrates the alignment of content-assessment-pedagogy towards the intended learning outcome (Kandakatla & Streveler, 2015). Phases of the framework which involve problem scoping, forming interdisciplinary teams, exposing real-world problems, doing foundational workshops, and coming up with solutions bring a constructive approach to learning. This structured method aims to help students with diverse technical backgrounds collaborate and close knowledge gaps. The learning outcomes that are grounded in the learning theories ensure profound skills of team collaboration, abstraction, and innovation. Problem-Based Learning (PBL) integration enables the students to be self-directive and reflect on the learning experiences in each stage (Vijaylakshmi et al., 2022). The formative assessments and surveys help course designers to re-iterate for better design in the future. The innovative solutions developed at the end of the process show the student's ability to adapt a multidisciplinary learning experience. This happens by exchange of technical knowledge from students belonging to multiple disciplines (Kandakatla et al., 2020). The objective of producing new age engineers for modern era can be fulfilled by inculcating the multidisciplinary learning experiences by integrating Problem-Based Learning approach.

VI. CONCLUSION

The study illustrates that the demands of multidisciplinary learning are addressed by integrating Problem-Based Learning (PBL) into the electric vehicle (EV) course by putting a supporting structure in place. The challenges with the students' problem-solving abilities are also addressed. Pre- and post-course tests, group problem-solving, and peer teaching help engineering students from diverse backgrounds enhance their knowledge of the concepts related to EV and improve their problem-solving skills. The results show that effective collaborative skills, a high level of engagement, and innovative solutions to ill-structured problem statements emphasize the significance of multidisciplinary learning. The survey, assessments, and feedback from both students and instructors highlight further development and modifications in the course design in terms of content, assessment, and pedagogy. This study can be extended to another multidisciplinary course in various disciplines in the future.

ACKNOWLEDGMENT

I would like to thank the management of KG Reddy College of Engineering and Technology for supporting the multidisciplinary learning among students and encourages us to conduct these studies.

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