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Effect of project-based learning method for improving students problem-solving ability in the experiment of power electronics course

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Abstract— **This paper examines the integration of the CDIO (Conceive, Design, Implement, Operate) framework in Mechatronics curriculum. CDIO revolutionizes technical education by emphasizing project-based learning (PBL) and practical experiences, fostering skills, attitudes, and problem-solving abilities for real-world challenges. The Power Electronics course for fourth-semester students, aligned with CDIO, covers semiconductor devices, converters, rectifiers, choppers, inverters, and specialized machine switching circuits. Being an outcome-based education (OBE) curriculum, two of its outcomes focuses on applying gained knowledge. PBL was implemented to achieve the outcome of the course among students. During the process of implementation, students demonstrated diverse outcomes. In the proposed case study, Set A effectively accomplished problem identification, simulation, and hardware implementation. In contrast, Set B had difficulties pertaining to the integration of hardware components. This study highlights the varied dynamics observed in student involvement and academic achievement within the context of project-based learning. By doing a comparative analysis of the outcomes between Set A and Set B, valuable insights may be gained to enhance instructional techniques. This statement highlights the significance of utilizing the CDIO framework's principles to improve project-based learning and better the overall educational experience in future deployments.**

Keywords— Power Electronics, CDIO, Project Based Assignment, T-test.

I. INTRODUCTION

IN the continuously evolving world of education, the need for effective teaching and learning techniques have become more important than ever. Even though the traditional learning methods continues to dominate the classrooms, many educators and researchers are recognizing the limitations of such passive learning methods. Students now desire personalized and interactive learning environments that cater to their individual needs, interests, and aspirations, so to address these challenges, the educators are trying to implement innovative methodologies that prioritize active student involvement Marasco et.al (2013). This is where active learning techniques step in to revolutionize the educational paradigm. Active learning encourages students to take an active role in their learning journey, transforming them from passive observers to active participants. It empowers learners to explore concepts actively, engage with their peers, and build practical skills that extend beyond memorization. Project-based learning (PBL) is a specific pedagogical approach that falls under the umbrella of active learning Kristina et.al (2014). In PBL, students engage in in-depth investigations of real-world problems or challenges. They work collaboratively to design and complete projects that require them to apply their knowledge and skills to solve authentic issues. Projects are not an afterthought in the curriculum; rather, they constitute the centerpiece. In PBL, students are presented with open-ended questions to which they must arrive at a solution. They do not just remember the questions in their books and write them down on the test; instead, they must come up with a real-world solution Thomas JW (2000) and Krajcik. J et.al (2005). PBL has shown effects on the students who are less confident on themselves and who struggle to learn from books. Since these projects are mostly done as a team, the sustained team interactions help them to come up with different solutions and make them ready for the professional career they have ahead, Mergendoller JR et.al (2006) and Fusic et.al (2022). PBL involves both vertical learning which is subject-wise knowledge and horizontal learning that is acquiring generic skills, it not only helps the students to get a deep knowledge in their subject but also gain experience through hands on work experience which is useful for them to solve the real-world problems in the future Gary Kevin (2015) and Hella (2006). It has been determined through studies on PBL that this strategy has benefited students academic performance. Cognitive psychologists claim that when knowledge and concepts are actively utilized, new knowledge is created Anitha et.al (2022). The content that is taught and the manner in which it is

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delivered are crucial for both successful teaching and learning and for the advancement of pupils in all areas of skill development. It is believed that project-based learning (PBL) is a potential strategy for enhancing student learning in higher education. With an emphasis on student outcomes, empirical research on project-based learning have been evaluated Thiruvengadam et.al (2022). The CDIO framework offers a paradigm change from conventional instruction to a dynamic and immersive learning experience, representing a transformational approach to engineering and technical education. The essential concepts of "Conceive, Design, Implement, Operate," or CDIO, serve as a compass for training tomorrow's engineers and innovators Fusic et.al (2022). By fostering a comprehensive set of abilities, it gives students the technical knowledge they need as well as the capacity to tackle real-world problems through practical projects and group problem-solving Anitha et.al (2018). In order to encourage creativity, flexibility, and a thorough awareness of the nuances of engineering practice, this educational philosophy places an emphasis on the practical application of ideas A. Chuchalin et.al (2015) and Anitha et.al (2023).

Our research paper's objective is to investigate the impact of project-based learning on students' learning outcomes in power electronics. "It is based on the analysis of efficiently achieving the two apply outcomes where students will be able to choose appropriate converter technique to control different drives in industrial applications and to select and integrate suitable electrical drives for motion control applications such as Machine tools and Industrial robotics. In this paper, the Chapter I covers the introduction part and related works. Chapter II states the proposed work, Chapter III details about the experimental case study of our proposed work and analysis of the individual student's assignment. Chapter IV provides the Result and analysis based on two groups involved in the PBL. Chapter V states the conclusion and future work.

II. Proposed Work Approach

The integration of the revolutionary CDIO framework exemplifies educational innovation and brings about a revolution in technical education, paving the way for a unique approach to achieving greatness. This innovative method revolutionizes the domain of technical education by placing significant focus on project-based learning and experiential learning opportunities. The CDIO framework is important in generating graduates with the necessary skills, attitudes, and problem-solving aptitude required in real-world situations, in addition to theoretical knowledge. The fundamental nature of engineering practice, where students progress from being merely learners to skilled practitioners, is reflected in the CDIO framework. The curriculum integrates multidisciplinary projects, cooperative cooperation, effective communication, ethical issues, and a sense of sustainability to provide students a comprehensive and flexible skill set. The Power Electronics course, a crucial part of the fourth-semester mechatronics engineering's curriculum, is at the center of this shift. With regard to semiconductor devices, converters, rectifiers, choppers, inverters, and the intricate workings of specialized machine switching circuits, this course offers a thorough grasp of power electronics. The course, which is grounded on the CDIO framework, provides the basis for real-world application and hands-on learning. The course's five outcomes, of which two CO 5 and CO 6 are of the apply-based sort, serve as a focus point.

TABLE 1
POWER ELECTRONICS COURSE OUTCOME FOR PROPOSED WORK

CO no	Course Outcome Statement	CO type
CO 5	Choose appropriate converter technique to control different drives in industrial applications.	Apply
CO 6	Select and integrate suitable electrical drives for motion control applications such as Machine tools and Industrial Robotics.	Apply

These results highlight the need of applying learned information to real-world problems, reflecting the CDIO concept. In the fourth-semester classroom of mechatronics engineering, a novel strategy was employed to guarantee the successful accomplishment of these goals. With a baseline knowledge of analog electronics and electrical machines, 66 students were given a project-based learning approach that was specifically designed for them. Through cooperation, project management, and collaborative abilities, the pedagogical model not only promotes vertical learning but also makes horizontal learning possible. Students established three-person teams in a symphony of interactions, creating 22 groups that each served as a miniature representation of the engineering teams seen in the real world. The incorporation of fundamental ideas into projects embodies the spirit of power electronics and its useful applications. Three steps were purposefully chosen to split the project-based assignments: choosing a problem statement, MATLAB simulation, and hardware implementation.

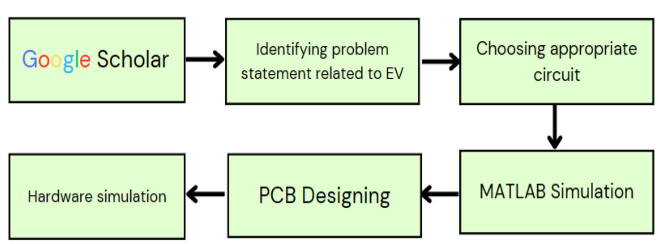

Fig 1. Proposed work Flow Diagram

Students set out on a quest that required them to solve problems, validate theories, and fabricate things with their hands. The iterative nature of the assignments aligns with the concepts of the CDIO framework, promoting a thorough understanding of the subject. In conclusion, the use of the CDIO framework demonstrates its steadfast dedication to holistic education. Students transform into skilled engineers equipped to meet the difficulties of the changing engineering scene thanks to this synergistic approach.

TABLE 2
RUBRICS FOR ASSIGNMENT ASSESSMENT

Project-based Learning Rubric

Content	3 (Proficiency)	2 (Developing)	1 (Beginning)
Problem statement	• Clearly defines and articulates the problem to be addressed. • Provides a thorough analysis of its significance and potential impact.	• Clearly defines the issue and provides a cursory analysis of its importance. • It could be difficult to understand its effects fully.	• There is no precise articulation or analysis of the problem, only a general definition. • Limited understanding of its significance.
MATLAB simulation	• Develops a well-structured and accurate MATLAB simulation that effectively models the problem. • Demonstrates a deep understanding of relevant simulation techniques.	• Constructs a MATLAB simulation with some comprehension gaps or small inaccuracies that only partially reflects the issue.	• Presents a basic or flawed MATLAB simulation, with significant errors or limited understanding of relevant techniques.
Prototype and implementation	• Designs and prototyped a fully functional circuit board to successfully solve the identified problem. Demonstrating innovation and technical proficiency in PCB design.	• Designed and manufactured a PCB prototype that partially solves the problem, but some technical aspects need refinement or improvement.	• Presents a PCB prototype with significant defects, innovation, technical understanding, or lack of functional elements.
Collaboration and Communication	• Actively collaborates within the team, effectively communicating ideas, progress and challenges. Participate constructively in discussions and presentations.	• Engages in some degree of collaboration, communicating ideas and progress, but may have difficulty communicating or participating effectively	• Limited cooperation and communication, difficulty communicating ideas, making progress, or engaging in meaningful discussions.

The CDIO framework is more than simply a paradigm for education; it also represents a way of thinking that produces graduates who are prepared to change the world. These tasks creating a problem statement, modelling circuits, and finally producing hardware provided students with essential hands-on experience and deepened their understanding of the principles. The harmonious coexistence of theoretical understanding and real-world application was skillfully fostered.

III. CHOPPER CONTROLLED DC DRIVES CASE STUDY

Electric drive systems that regulate the direction and speed of DC motors include chopper-controlled DC drives. To precisely adjust the motor's speed and torque, these drives use power electronics devices known as choppers or DC-DC converters to convert a set DC voltage to a variable DC voltage.

There are three types of chopper circuits

1) Boost converter – step up converter
2) Buck converter – step down converter
3) Buck – Boost converter – step up/down converter

A boost converter is a form of DC-DC power converter used to raise DC input voltage to a greater level of output. It functions by carefully switching a diode and an inductor. When the switch is off, the energy that the inductor had been storing when it was on is transferred to the output using a diode. The output voltage may be adjusted by adjusting the duty cycle of the switch. The converter effectively steps up voltage levels in a variety of systems, including battery-powered gadgets and renewable energy sources.

1. BOOST CONVERTER

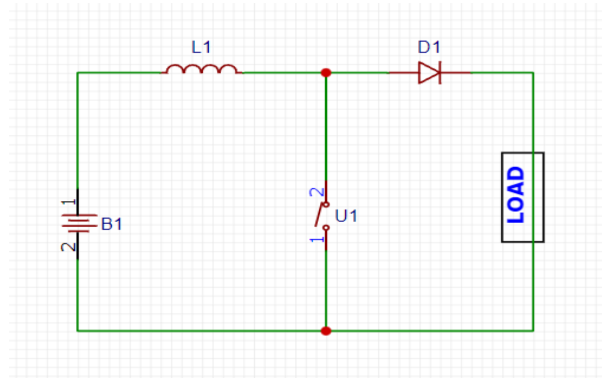

Fig 2 Boost converter circuit in proteus software

Although it can have issues with input current ripple and electromagnetic interference, it has advantages in terms of simplicity, efficiency, and voltage control. Considerations for design include the load current, input voltage range, switching frequency, and efficiency standards.

The basic formula for the output voltage of a boost converter is given by:

$$V_{out} = \frac{D}{1 - D} X \, V_{in}$$

Where,

- Vout is the output voltage.
- D is the duty cycle of the switch (ratio of ON time to total period).
- Vin is the input voltage.

2. BUCK CONVERTER

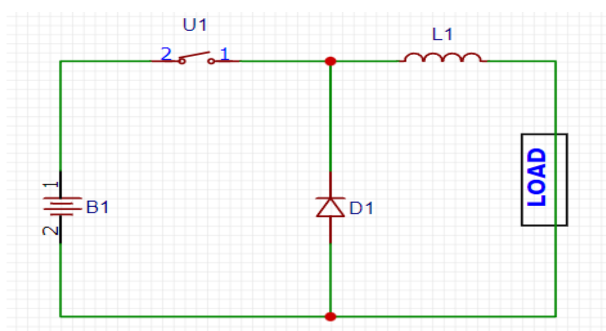

Fig 3 Buck converter circuit in proteus software

Another one of the DC-DC power converter called a buck converter is one that steps down a greater DC input voltage to a lower output voltage. Operating by carefully regulated transistor switching, it sends energy to the load through a diode during the switch-off phase after storing it in an inductor during the switch-on phase. The duty cycle of the switch affects the output voltage of the converter, with greater duty cycles resulting in lower output voltages. Buck converters are widely utilized in many different applications, such as battery charging systems, electronic device voltage control, and effective power management. They have minimal output voltage ripple, excellent efficiency, and simplicity. To achieve the required results, design elements like switching frequency, load current, and inductor selection are crucial.

The basic formula for the output voltage of a buck converter is given by:

$$V_{out} = D\ X\ V_{in}$$

Where,

- Vout is the output voltage.
-
- D is the duty cycle of the switch (ratio of ON time to total period).
- Vin is the input voltage.

3. BUCK – BOOST CONVERTER

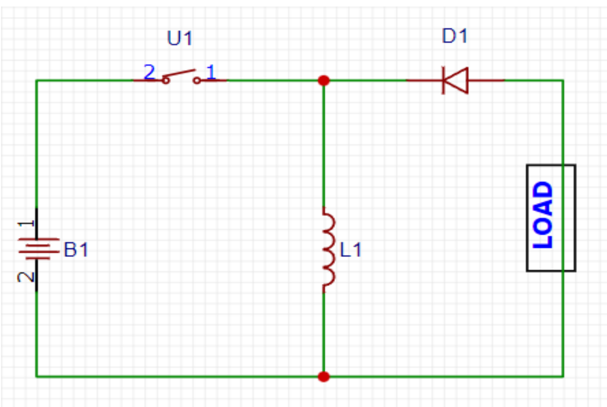

Figure 4 Buck Boost converter circuit in proteus software

A buck-boost converter is a type of DC-DC power converter that can both step up and step down a DC input voltage to produce a desired output voltage. It achieves this by intelligently controlling the transfer of energy between an inductor and a capacitor through a switch. During the switch-on phase, energy is stored in the inductor, and during the switch-off phase, the stored energy is released to the load through the capacitor. This converter is versatile and suitable for applications requiring both voltage reduction and voltage increase, such as battery-powered systems and portable electronic devices. Its output voltage is determined by the duty cycle of the switch, and its design involves considerations like efficiency, component selection, and operating modes (continuous or discontinuous). The buck-boost converter's adaptability makes it a valuable tool in various power management scenarios.

IV. IMPLEMENTATION OF PROPOSED WORK

The implementation stage was a crucial milestone in the effort to incorporate the CDIO framework into the curriculum Mechatronics Engineering. Through project-based learning, it was intended to promote practical knowledge and competence in the field of power electronics. This practical approach sought to provide students with the abilities required to deal with engineering difficulties in the real world. The task was broken down into three distinct phases: choosing a problem statement, simulating a circuit in MATLAB, and implementing hardware. An interesting difference in student performance became apparent as the project progressed. While some students were able to complete all phases of the project problem identification, circuit simulation, and hardware integration others had difficulties while moving from simulation to hardware integration. The students were divided into two groups in order to obtain insight into these variations: SET A, which included those who had trouble implementing the hardware and SET B, which included those who successfully completed all project phases.

SET A assignment report demonstrated an equally solid comprehension of the issue statement. The MATLAB simulations were well-designed, and the results were as predicted. For this group, the hardware implementation phase presented difficulties. Their transfer from simulation to hardware was characterized by a few irregularities, which hindered their ability to realize their circuit designs in a physical form.

A.1 Assignment Title: Dual Active Bridge (DAB) Converter Advances: Operation, Control, and Design Considerations for High-Frequency Power Conversion Applications using the MATLAB 2020 platform with Simulink. The SET A students who has developed the simulation model and submitted the assignment report. Whereas the SET B students developed the Simscape model further to simplify the circuit and interested in learning more about simulation work and employing the results in real-world applications. Further students will change the simulation model by calculating the R, L, and C parameter for their application and producing results for the same once the findings have been replicated as in the main article. In order to assess their developed converter utilizing a circuit validation setup that was available in the lab, the students expanded their horizons by merging simulated models onto hardware printed circuit board (PCB) models. On the other hand, the assignment report submitted by SET B showed thorough comprehension of the issue description and detailed MATLAB simulations. These simulations were not only well-done, but they also closely matched the principles covered in class. The ensuing hardware implementation phase served as a demonstration of their capacity to convert abstract concepts into real-world prototypes, as shown by the granular images and technical explanations.

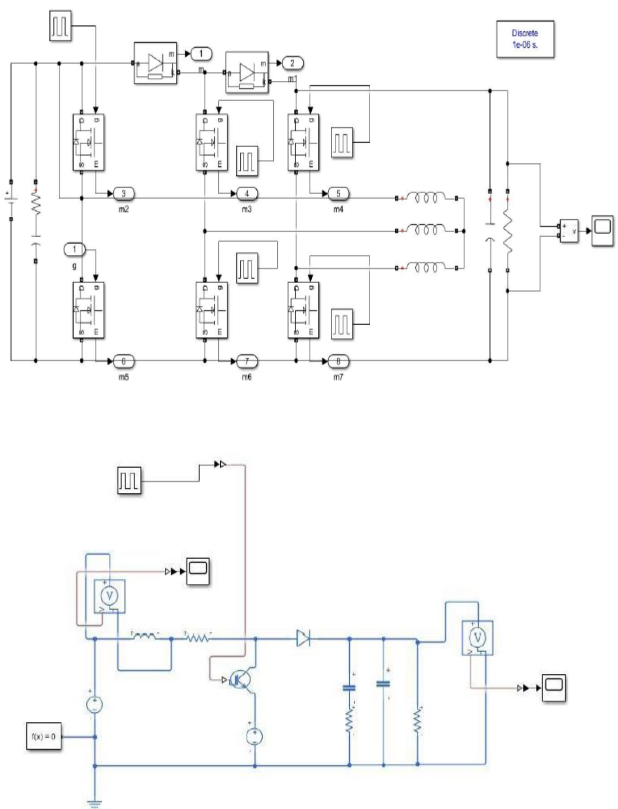

Fig 5 a, b: MATLAB Simulink and Simscape Model developed by the Set B students

A.2 Assignment title: Efficient and Compact Design of LDC using Buck-Fly back Hybrid Converter

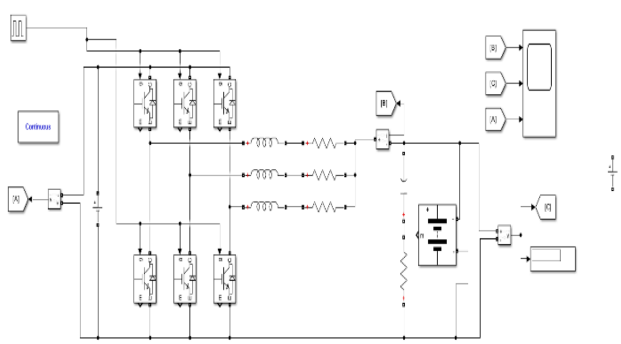

Fig 6: MATLAB Simulink model for Fly back circuit

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Further the Pulse width modulation (PWM) control signals are used to turn on the relay and control six power components while the integrated circuit is in inverter mode. The relay is turned OFF and, depending on the load conditions, a single-phase or interleaved control mechanism is used to manage the power devices while the proposed integrated circuit is operating in the converter mode. In comparison to single-phase control, interleaved control's efficiency rises as the load exceeds 2.4 kW. As a result, the proposed hybrid control method is used to control the boost converter. Because the load exceeds the power ratio

switching point for the specified voltage ratio, the converter is controlled in interleaved mode, which considerably reduces current ripple and, consequently, losses. As opposed to two-phase interleaved control, which results in additional conduction and switching losses, single phase control regulates the converter when the load is less than the power ratio's switching point for the specified voltage ratio. The load situation determines the transition point, which is then implemented in the interrupt service routine (ISR) for the flow diagram of the proposed control for the proposed integrated circuit in boost converter mode. From the figure 3 and 4, the SET B students further develop the tinker cad circuit design and PCB layout design to complete the hardware layout of their proposed simulation work.

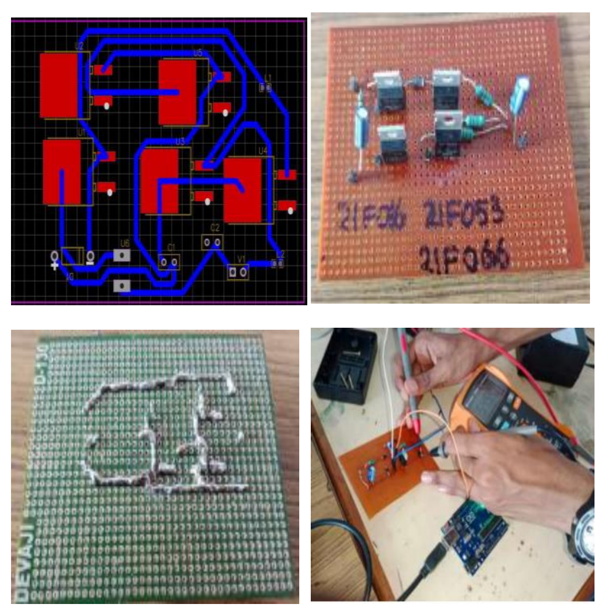

Fig 7: PCB Layout and component design for the proposed simulation work by SET B students.

B.2 Assignment title: Efficient and Compact Design of LDC using Buck-Fly back Hybrid Converter

We rigorously evaluated the grades on the assignments for both groups in response to this disparity. The goal of this investigation was to determine how finishing the complete assignment affected the students' general performance.

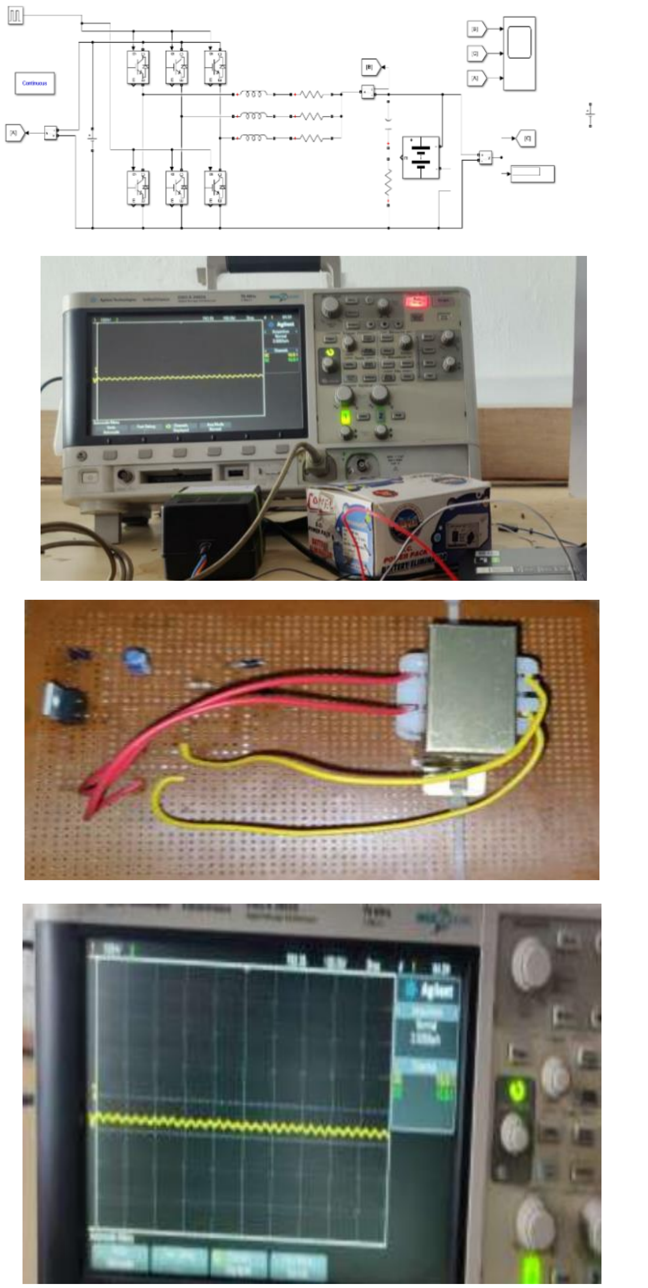

Fig 8: For Assignment study B2 Simulation model, PCB layout, Hardware implementation and Validation by SET B

It is carefully looked through each of their work examples to support our results. It was clear from examining the work samples Set B's success was due to their successful fusion of theoretical ideas with real-world applications. The challenges Set B had in moving from simulation to hardware brought to light the significance of bridging this gap through targeted advice and assistance. These results highlight how project-based learning is diverse. The different results between the two groups highlight the crucial importance of ongoing mentoring and practical experience in developing engineering abilities. In conclusion, the project-based learning framework's implementation phase gave us a chance to observe the dynamic nature of student involvement and performance. Our comprehension of the subtle differences in students' learning experiences has increased as a result of the divergent paths of Set A and Set B. our understanding will guide our future efforts to improve our methods and provide focused help, ensuring that every student may benefit fully from our cutting-edge teaching strategy.

V. Results and Discussion

This section summarizes the findings of our study on the effects of Project-Based Learning (PBL) in the power electronics Course with a particular emphasis on three main steps that is Circuit Design, Simulation using MATLAB, and prototype (PCB). There are two set of students namely Set A and Set B. The circuit design phase was successfully completed by both groups of students, demonstrating their comprehension of power electronics concepts and component choice. Set A continued with the MATLAB simulation, and examination of the simulation results showed a noticeable improvement in their comprehension of power electronics fundamentals and the successful modelling of their circuit designs. While Set A had finished the circuit design and MATLAB simulation, Set B had moved on to the hardware/prototype development stage. The projects created by SET B displayed substantial practical skill growth and produced the best results in terms of circuit functionality and performance.

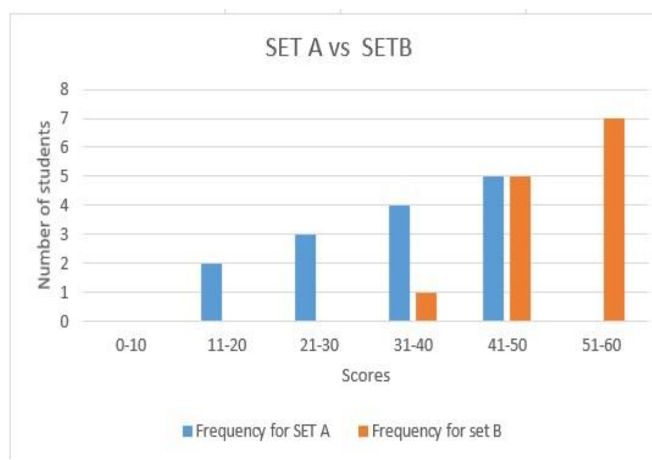

Fig 9: CO Mark comparison for both SET A and SET B

Here, the frequency refers to the scores of the respective sets. Analysis of Sets A and B in comparison showed that Set B's advancement to the hardware/prototype step resulted in a greater project effectiveness and successful practical implementation. Set B's mean scores were much higher than Set A's, according to quantitative analysis based on test results and project evaluations, demonstrating a definite link between completing all three processes and increased performance.

TABLE 3
T TEST HYPOTHESIS FOR PROPOSED CASE STUDY BATCHES

Null Hypothesis		$H_o: \mu_1 - \mu_2 = 0$
Alternate Hypothesis		$H_1: \mu_1 - \mu_2 \neq 0$
T-Value	**DF**	**P-Value**
-3.685	38	0.00035

Additionally, Set B indicated greater comprehension of power electronics applications and greater confidence in circuit design and debugging, highlighting their higher satisfaction with the project-based learning approach.

4.1 T test results:

The analysis aimed to determine if there were any significant differences in their performance-based learning outcomes in Task III of the project-based course. The t-test is a powerful statistical tool used to compare the mean of two groups and determine if the observed difference is statistically significant. In our case, we employed two sample t-test to assess whether the learning outcomes are significantly different between set A and set B.

TABLE 4
T TEST TWO SAMPLE HYPOTHESIS FOR PROPOSED CASE STUDY

Assignment 3			**Assignment 2**		**Assignment 1**	
Description	**SET A**	**SET B**	**SET A**	**SET B**	**SET A**	**SET B**
Mean	38.4	42.4	31.15	33.35	27.2	25.4
Variance	15.62	7.936	200.5	154.8	101.9	80.25
Observations	20 Students batch		20 Students batch		20 Students batch	
Pooled Variance	11.77894737		177.6078947		91.05263158	
df	38		38		38	
t stat	-3.68558770		-0.522025295		0.59652171	
P(T<=t) one tail	0.000354494		0.302341313		0.277182062	
T critical one tail	1.38595446		1.68595446		1.68595446	
P(T<=t) two tail	0.000708989		0.604682625		0.554364125	
T critical two tail	2.024394164		2.024394164		2.024394164	

Inference

- The mean score for Set A was 38.4, while the mean score for Set B was higher at 42.4. The calculated t-statistic of -3.685 indicates a significant difference between the two sets in terms of their mean scores.
- The p-value associated with the t-test is very small (approximately 0.000354), which is less than the common significance level of 0.05. This suggests strong evidence to reject the null hypothesis, indicating that there is a statistically significant difference in the mean scores between Set A and Set B.

Based on the t-test results, we can infer that Set B (students who completed the entire Assignment III) has achieved statistically significantly higher mean scores compared to Set A (students who completed only up to MATLAB simulation). This suggests that the additional step of completing the prototype in PCB (as done by Set B) may have positively impacted the learning outcomes, leading to higher scores.

4.2 Opinions gathered from both sets:

<u>SET A</u> (Simulation step):

- Students in Set A expressed that the simulation step helped them gain a deeper understanding of power electronics principles and how different components interact in a circuit.
- Set A's students noted that analysing simulation results allowed them to identify potential issues and refine their designs before moving to the hardware implementation phase.

<u>SET B</u> (prototype step):

- They emphasized the significance of the hardware step, which allowed them to validate their theoretical designs and witness the practical functioning of their circuits.
- Many students acknowledged the importance of teamwork in the hardware phase, highlighting effective communication and collaboration in achieving successful outcomes.

The t-test results demonstrate that building a PCB prototype in the project course contributes to a significant improvement in learning outcomes compared to stopping at the MATLAB simulation step. These findings underscore the pedagogical value of integrating hands-on prototyping activities into educational contexts. The variability identified in learning outcomes suggests that the experience- and application-centred nature of hands-on prototyping has the potential to enhance student engagement and mastery of complex concepts. In turn, this contributes to a more inclusive and inclusive educational experience that fosters critical thinking, problem-solving skills, and creativity. However, it is imperative to recognize the limitations of this study. The specific sample size and assignment context may affect the generalizability of our findings. Future research efforts may delve deeper into the nuanced factors that contribute to the observed differences and explore additional aspects of the impact of project-based learning.

VI. CONCLUSION

In this study, we set out to explore the effectiveness of project-based learning in improving student learning outcomes, with particular focus on the transition from the MATLAB simulation phase to the simulation phase. Prototype segment to PCB. Through rigorous data analysis and interpretation, we have gained valuable insights into the impact of hands-on prototyping activities on student achievement. The proposed comparative analysis, based on a two-sample t-test, found a significant difference in learning outcomes between set A and set B. The t-test results clearly demonstrate It is clear that students who participated in the prototype at the PCB stage achieved a higher average score than their peers who finished their project at the MATLAB simulation stage. This finding emphasizes the pedagogical value of practical applications in the learning process, favoring the integration of hands-on activities to facilitate deeper understanding and retention of knowledge. As we navigate the context of teaching methods, the findings of this study offer implications for instructional design, curriculum development, and instructional strategies. By highlighting the transformative potential of real-life prototyping, we advocate a paradigm shift in educational practice, fostering an environment that allows students to thrive in an increasingly complex world Dynamic and connected.

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