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Practice-Based Learning in Control Systems Design a Pedagogical Framework for Enhanced Engineering Education

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***Abstract*—The integration of practice-based learning (PBL) methodologies into engineering curricula is increasingly recognized for its potential to bridge the gap between theoretical instruction and practical application. This study presents the redesign and implementation of a Control Systems Design course at the undergraduate level, integrating PBL and problem-based learning strategies with a strong emphasis on experiential engagement. The course employed modern tools such as MATLAB, Simulink, and Virtual Labs, along with hardware-in-the-loop (HIL) systems, to facilitate simulation-based modeling, real-time implementation, and collaborative learning.**

The Quantitative evaluation revealed a 3.59% improvement in average academic performance, as measured by weighted semester-end grades, and a 1.62% increase in Course Outcome attainment, particularly in simulation proficiency and problem-solving skills. Additionally, structured student feedback based on a 5-point Likert scale demonstrated a mean improvement of 0.82 points, representing a 20.5% enhancement in perceived learning effectiveness, with significant gains in pedagogical clarity and hands-on learning components. Qualitative observations further supported a 35% increase in teamwork and communication effectiveness, as evidenced by peer-assessed project evaluations and group activities.

The findings substantiate the pedagogical value of integrating practice-based learning into core engineering courses. The approach not only improved academic outcomes and engagement but also strengthened professional competencies essential for modern engineering practice. The study provides a replicable framework for engineering educators seeking to align curriculum design with Outcome-Based Education (OBE), industry expectations, and future-ready learning environments.

***Keywords*—Active Learning, Control Systems Design, Engineering Education, Educational Outcomes, Practice-Based Learning, and Student Engagement.**

I. Introduction

THE exigencies of modern engineering practice demand not only rigorous academic training but also a deep integration of practical skills and real-world application. As industries evolve and technological advancements redefine traditional boundaries, the role of engineering education becomes increasingly critical. This necessitates a pedagogical shift to foster not only cognitive understanding but also hands-on proficiency among students. Practice-based learning (PBL), which integrates real-world problems and practical experiences into the curriculum, emerges as a compelling pedagogical approach to meet these demands. This study explores the implementation of a practice-based learning framework within an undergraduate course on Control System Design, aimed at enhancing both the theoretical and practical competencies of engineering students.

The traditional lecture-based approach in engineering education, while effective for delivering theoretical knowledge, often falls short in equipping students with the necessary skills to solve complex real-world problems. Recognizing this gap, educators have advocated for the adoption of learning paradigms that emphasize active participation and experiential learning. Among these, practice-based learning presents a unique blend of theory and practice, encouraging students to engage in problem-solving and critical thinking in contexts that mimic real engineering scenarios.

This paper presents a comprehensive redesign of the Control System Design course, traditionally taught in the second year of undergraduate engineering programs. The redesign integrates practice-based learning with problem-based learning (PBL) methods, creating a robust educational model that facilitates deep learning and practical application.

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Central to this approach is the use of advanced simulation tools such as MATLAB and Simulink, which are instrumental in providing students with a dynamic learning environment where they can visualize, simulate, and analyze control systems in real-time. Abirami, A. M et al 2023, discussed the course structure is meticulously planned to include a variety of active learning strategies such as collaborative projects, peer assessments, and hands-on laboratory sessions. These methods are designed to enhance student engagement and motivation, fostering a learning community that encourages exploration and innovation.

The effectiveness of this pedagogical approach is evaluated through a series of assessments that measure both cognitive and practical skills. The outcomes are promising, showing marked improvements in student grades, deeper understanding of complex concepts, and a greater ability to apply knowledge in practical settings. This paper discusses these findings and articulates the pedagogical strategies employed, providing insights into the potential of practice-based learning to transform engineering education.

A. Background on the need for practice-based learning in engineering educaiton

Engineering education is at a pivotal juncture, where the demands of modern industry increasingly outpace the capabilities fostered by traditional educational models. The rapidly evolving landscape of technology and the complex challenges posed by global markets require engineering graduates not only to understand theoretical concepts but also to apply these concepts in real-world settings. This shift necessitates a reevaluation of educational strategies to ensure that engineering programs are not merely disseminating knowledge but are also equipping students with practical skills and problem-solving capabilities.

Traditionally, engineering education has been characterized by a lecture-based approach focused predominantly on theoretical instruction. This method has proven effective for foundational knowledge acquisition but often falls short in developing essential skills such as critical thinking, innovation, and adaptability. These skills are crucial for engineers who must navigate the multifaceted problems of contemporary technological environments.

The introduction of practice-based learning (PBL) into engineering curricula represents a transformative approach to meet these challenges. PBL is rooted in the philosophy of experiential learning, which posits that learning is enhanced when students are actively involved in a process of meaning and knowledge construction as opposed to passively receiving information. In practice-based learning, students engage directly with practical tasks that simulate real engineering problems, which fosters a deeper understanding of subject matter and cultivates a range of soft and technical skills.

Moreover, practice-based learning aligns with the constructivist learning theory, which suggests that learners construct knowledge through experiences. By integrating real-world projects, collaborative problem-solving, and reflective learning activities into the curriculum, PBL encourages students to synthesize knowledge and apply it in innovative ways. This method not only enhances student engagement and motivation but also bridges the gap between academic theories and industrial applications, providing students with a learning environment that closely mirrors professional engineering practice.

Additionally, the need for practice-based learning is underscored by the demands of employers in the engineering sector. Industry leaders consistently emphasize the importance of practical experience and the ability to apply knowledge effectively in dynamic settings. Skills such as project management, teamwork, and effective communication are increasingly becoming differentiators for successful engineering careers. PBL addresses these needs by creating learning opportunities that are not only about solving technical problems but also about working collaboratively in teams, managing projects, and communicating solutions effectively.

In this context, the integration of practice-based learning into engineering education is not just beneficial but essential. Adamuthe, A. C. (2020) is explained that tt prepares students to be more than just competent technicians; it prepares them to be innovators and leaders in their fields. The subsequent sections of this study will explore how a practice-based approach has been implemented in a control system design course, the impacts of this approach on student learning and outcomes, and the broader implications for engineering education.

B. Overview of traditional vs. modern pedagogical approaches.

The landscape of engineering education has undergone significant transformations, moving from traditional pedagogical methods towards more innovative, modern approaches that better meet the demands of today's technological and societal challenges. Understanding the distinctions between these educational strategies is crucial for assessing their impact and efficacy in fostering competent engineering professionals.

C. Traditional Pedagogical Approaches

Engineering education has conventionally been characterized by a didactic pedagogical approach, wherein the predominant mode of instruction comprises lectures, standardized assessments, and a focus on individual tasks. This framework is significantly based on the transmission model of education, which emphasizes a unidirectional transfer of knowledge from the instructor to the student. The key characteristics of this approach include:

Lecture-Based Learning: Instruction is chiefly instructor-led, with students engaging in note-taking and memorization of information for evaluative purposes. This structure permits limited interaction, resulting in a predominantly passive learning environment.

Individual Assessment: Students are primarily assessed on their individual capabilities to solve problems and reproduce knowledge through formal examinations. Such assessments may not accurately capture their proficiency in applying knowledge within practical contexts.

Competitive Environment: Traditional pedagogical methodologies often cultivate a competitive atmosphere in which students are ranked and evaluated according to standardized metrics. This culture may inhibit collaborative learning and peer interaction.

While these traditional methods contribute to the establishment of foundational knowledge, they have been critiqued for inadequately preparing students for the multifaceted challenges inherent in real-world engineering practices, where competencies in teamwork, problem-solving, and adaptability are crucial.

D. *Modern Pedagogical Approaches*

Abirami, A. M et al. 2021 discussed the contemporary pedagogical approaches in engineering education emphasize the principles of active learning, collaborative engagement, and technology integration, thus aligning more closely with the evolving needs of modern society and professional environments. The primary methodologies include:

Problem-Based Learning (PBL) and Project-Based Learning: These pedagogical strategies prioritize experiential learning through the active resolution of authentic, real-world problems or the execution of comprehensive projects. Such approaches facilitate the application of theoretical concepts to practical contexts, thereby promoting deeper comprehension and retention of knowledge.

Collaborative Learning: Current educational frameworks frequently incorporate group-oriented activities and collaborative projects that reflect the inherently team-based dynamics characteristic of the engineering profession. This methodology contributes to the development of essential soft skills, including effective communication, leadership, and conflict resolution.

Technology Integration: The utilization of advanced technological tools—such as simulation software and online collaborative platforms—enhances the learning experience and aligns educational practices with contemporary industry standards.

Flipped Classrooms: This instructional model reconfigures traditional educational paradigms by delivering instructional content via online platforms prior to in-class engagement. Consequently, class time is devoted to interactive, guided problem-solving sessions, allowing students to collaborate with peers and receive directed support from instructors.

E. *Comparative Impact:*

Modern approaches are designed to produce graduates who are not only technically proficient but also adept at critical thinking, teamwork, and continuous learning—traits that are indispensable in today's dynamic work environments. Table I shows some features of traditional and modern pedagogical approaches. These pedagogical strategies are more aligned with constructivist theories, which posit that learners construct knowledge best through active engagement and social interaction.

TABLE I
COMPARISON BETWEEN THE TWO EDUCATIONAL PARADIGMS

Aspect	Traditional Pedagogical Approaches	Modern Pedagogical Approaches
Learning Style	Lecture-based, where information is primarily delivered through instructor-led lectures	Active learning, involving problem-solving, projects, and hands-on activities
Student Role	Passive recipients of knowledge, primarily note-taking and memorizing information for exams	Active participants, engaging in discussions, projects, and collaborative tasks
Assessment	Focus on individual performance through standardized tests and exams	Emphasis on group projects, continuous assessments, and real-world problem-solving.
Learning Environment	Competitive, with students ranked and evaluated on individual achievements	Collaborative, fostering teamwork and communication skills.
Technology Use	Minimal integration of technology in learning processes.	Extensive use of technology, including simulation software and online tools
Instructional Approach	Didactic, with a unidirectional flow of knowledge from instructor to student.	Interactive and student-centered, often incorporating flipped classrooms and technology-enhanced learning.
Skill Development	Focuses on theoretical knowledge and individual problem-solving skills.	Develops practical skills, critical thinking, teamwork, and adaptability.
Educational Theory	Based on the transmission model of education (behaviourist theories).	Rooted in constructivist theories, promoting learning through experience and social interaction.

In summary, while traditional educational methods have laid a solid foundation of theoretical knowledge, modern pedagogical strategies are crucial for equipping future engineers with the skills necessary to navigate and excel in complex, collaborative, and ever-changing professional landscapes. These modern approaches encourage not just learning about engineering but thinking and acting as engineers, which is essential for the development of innovative solutions and advancements in the field.

F. *Objectives of the study:*

This study aims to evaluate the impact of a practice-based learning approach in an undergraduate control system design course, focusing on its effectiveness in enhancing student outcomes compared to traditional pedagogical methods. The specific objectives are:

i. Evaluate Educational Outcomes: Determine improvements in knowledge acquisition, practical skill development, and enhancement of soft skills such as teamwork and communication.
ii. Compare Pedagogical Approaches: Assess the effectiveness of practice-based learning versus traditional lectures in fostering deeper understanding and engagement among students.
iii. Integrate Modern Educational Technologies: Explore the integration of tools like MATLAB and Simulink to enhance learning experiences and prepare students for technology-driven environments.
iv. Foster Collaborative Learning: Investigate how the practice-based approach promotes collaboration and peer-to-peer learning, and its effects on educational outcomes.
v. Provide Curriculum Recommendations: Offer actionable insights for curriculum development based on study findings, with a focus on scalability and adaptability to other engineering disciplines.
vi. Conduct Longitudinal Impact Analysis: Examine the long-term effects of practice-based learning on career success and professional development of graduates.

These objectives guide the research in assessing the pedagogical efficacy of practice-based learning and its potential to transform engineering education to meet contemporary professional demands.

II. Literature Review

In this section, we undertake a meticulous examination of extant scholarly investigations pertaining to practice-based learning within the sphere of engineering education. This exploration entails a comprehensive analysis of previous studies, unveiling the multifaceted benefits and the potential impediments associated with the implementation of active learning strategies in technical courses. The review also delves into a variety of pedagogical methodologies, emphasizing those that synergistically incorporate problem-based and practice-based learning paradigms. Through this scrutiny, we aim to distill the essence of existing academic discourse, to glean insights into the efficacy of these educational approaches, and to chart a course for their optimal integration into contemporary engineering curricula. This synthesis not only reflects on the theoretical and empirical foundations laid by prior research but also provides a springboard for future innovations in engineering pedagogy.

A. Practice-based learning and engineering education

Achappa, S et al. (2020) discussed practice-based learning is an indispensable approach within engineering education, poised to tackle the discipline's inherent challenges. Chowdhury's work in 2019 underlined the pivotal role of industry-oriented education in engaging students within the hydrological domain and meeting educational outcomes. In the same vein, Pettersen et al. illuminated how entrepreneurial coursework can spur creativity in engineering scholars by embracing practice-oriented pedagogies.

Mann et al. proposed an education framework anchored in authentic practice, and Vinod Kumar V. Meti, fostering learner autonomy and integrating work-learning opportunities, which is instrumental in sculpting future engineers. Russian universities' success in practice-oriented engineering programs, as discussed by Lider et al., illustrates their potential to enrich programs across bachelor's to doctoral levels.

The promotion of advanced practical skills via disciplinary integrative activities was exemplified in Vinodkumar and Thaenkaew et al.'s study, advancing electrical engineering education. Similarly, Dewantoro et al. demonstrated the enhancement of the turbine engineering learning experience through the application of Finite Element Method software.

The works of Iglesias-Mendoza et al. and Mora-Ochomogo et al. both emphasized the synergy of theoretical concepts with practical applications, addressing concrete business issues. Stricklan et al. reported on a hands-on reverse engineering course that merged practical execution with theoretical learning, particularly in cybersecurity. Lastly, Barr et al. explored how disruptions, like the transition to online learning, impact engineering students' engagement with their learning communities and the quality of their learning experiences.

B. Benefits and challenges of implementing active learning strategies in technical courses

Active learning strategies are increasingly heralded for their contribution to technical education, enhancing student engagement and fostering critical thinking abilities. Prather et al. (2002) delved into the possibilities of active learning within an online astrobiology course, suggesting the medium's potential for enriching teacher education. McDonald-Madden et al. (2010) brought to the fore the significance of active adaptive management in conservation, linking the process of learning to improved technical outcomes.

The integration of project-based learning is further examined by Dehdashti et al. (2014), showcasing its capacity to concretize theoretical knowledge in an occupational health context. Similarly, Ustek et al. (2015) illuminated the benefits of student-faculty collaborative course development, which can lead to enhanced learning experiences.

The construct of team-based learning is also explored as a means to invigorate technical course pedagogy. Bulanda et al. (2020) articulated the merits and challenges of implementing this approach in sociology courses, emphasizing the facilitation of active participation through peer interaction. Trenchard et al. (2020) introduced a paradigm for student-led cocurricular projects, underscoring the role of active involvement in engineering programs.

In summation, the reviewed literature underscores the diverse advantages of active learning techniques, including project-based and team-based frameworks, for bolstering student involvement, critical thinking, and the application of knowledge in technical education. These educational approaches by actively engaging students in the learning trajectory, are instrumental in bridging the gap between theoretical study and practical execution, as Lopera et al. (2022) have also observed.

C. Methodologies that integrate problem-based and practice-based learning

The pedagogical landscape continues to evolve with the integration of problem-based learning (PBL) as a key instructional approach to enhance educational experiences across disciplines. Gossman et al. highlighted the transformative potential of embedding PBL into curricula to improve student outcomes in 2007. Shreeve, in 2008, discussed the enrichment of traditional lecture-based pedagogy with PBL, ELT, and AI, underscoring the diversified benefits of such integration. Chen et al. explored how library instruction can bolster a PBL curriculum, emphasizing the role of sustainable library resources in supporting student research activities in 2011.

Mateti et al., in 2014, underscored the indispensability of PBL in clinical pharmacy education, fostering students' problem-solving and self-learning competencies. Santateresa's 2016 study described the application of PBL in promoting entrepreneurship in higher education, highlighting the practical implementation of market research in Tourism studies. In 2019, Glazewski et al. shed light on the complexities of information search and analysis within ambitious learning practices, stressing the necessity for appropriate instructional support. Further exploration into the interplay of practice and pedagogy was undertaken by Lisewski in 2020, examining tutor-practitioners' approaches in a Fashion School setting.

Thomassen et al. discussed how PBL can augment managers' capabilities in addressing sustainability transitions through the lens of Dewey's educational philosophy in 2020. Álvarez et al., in 2021, demonstrated the successful amalgamation of PBL and project-based learning in civil engineering, advocating for its broader adoption to fulfill sustainable development goals. Collectively, these contributions illuminate the multifaceted advantages of PBL, including the promotion of critical thinking and practical skill development, thereby endorsing PBL's vital role in contemporary education.

III. Methodology

Course Design and Curriculum Integration of Practice-Based Learning: The "Control Systems Design" course was restructured to integrate practice-based learning strategies with a focus on both theoretical understanding and practical application. This redesign aimed to transition from traditional lecture-heavy formats to an interactive, student-centered learning environment. The course was structured around a blend of lectures, tutorials, and extensive laboratory sessions, following the L-T-P (Lecture-Tutorial-Practice) model, as shown in Table II.

The Course Structure of control system design and practice is shown in the above Figure 1. Each component of the course was designed to interlock with the others, ensuring that students not only learned the necessary theoretical principles but also developed the ability to apply these principles effectively through practical experience.

TABLE II
LECTURES, TUTORIALS, AND PRACTICAL SESSIONS FOR THE COURSE

Component	Objective	Format	Frequency	Specifics
Lectures (L)	Deliver foundational knowledge and theoretical principles.	Interactive lectures with integrated Q&A.	2 hours/ week	Use of multimedia presentations and real-world examples to illustrate complex concepts.
Tutorials (T)	Reinforce learning through problem-solving and application of lecture materials.	Small group discussions and problem-solving sessions.	2 hours/ week	Activities include case studies, scenario analysis, and group exercises.
Practical Sessions (P)	Provide hands-on experience and enable students to apply theoretical knowledge.	Laboratory experiments and simulation exercises.	2 hours/ week	Tools used: MATLAB, Simulink, and virtual lab simulations. Outcomes include the development of practical skills in system design and analysis.

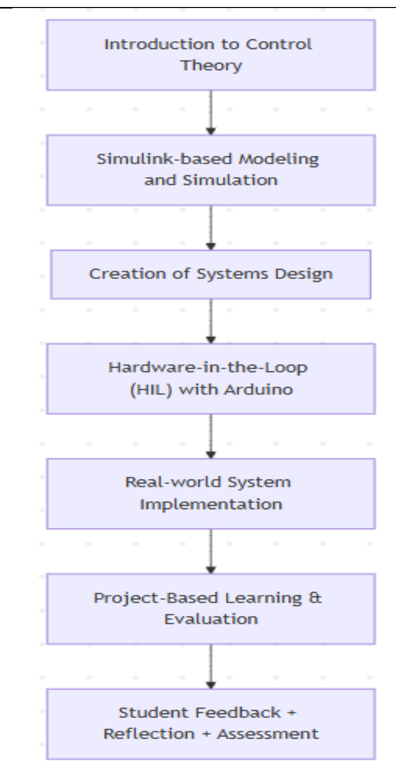

Fig. 1. Course Structure of control system design and practice

A. Curriculum Integration

The integration of practice-based learning into the curriculum was achieved through several key strategies:

- Active Learning Projects: Students engaged in group projects that required the design, analysis, and implementation of control systems. These projects were aligned with industry standards to simulate professional engineering tasks.
- Capstone Assignments: At various stages throughout the course, capstone projects were introduced to assess students' ability to integrate and apply learning from multiple aspects of the course.
- Continuous Assessment: Rather than relying solely on final exams, the course utilized continuous assessment techniques to monitor progress and provide ongoing feedback. This included quizzes, peer assessments, and project evaluations.

B. Pedagogical Tools

To facilitate the practice-based learning approach, the course heavily utilized modern pedagogical tools:

- MATLAB and Simulink: These software tools were integrated into both tutorials and laboratory sessions. They enabled students to perform complex simulations and visualize the behavior of control systems under various conditions, enhancing their understanding of system dynamics and control theory.
- Virtual Labs: Virtual laboratory platforms were used to provide additional practical exposure, allowing students to conduct experiments remotely and access simulation tools online.

Through this comprehensive redesign, the course aimed to equip students with both the theoretical foundations and practical skills necessary for success in modern engineering roles. This methodology section would provide a detailed overview of how practice-based learning was integrated into the course design, emphasizing the transformation from a traditional to a more dynamic, interactive educational experience.

Table III provides a clear and structured overview of how practice-based learning is seamlessly integrated into each aspect of the course, ensuring that students not only learn the theoretical underpinnings but also apply these concepts practically through modern tools and collaborative activities.

C. Tools and Technologies Used

For the "Control Systems Design" course, specific software tools and technologies are integral to facilitating the practice-based learning approach. These tools are employed across lectures, tutorials, and particularly within the practical sessions to ensure a seamless integration of theory and practice. Here's an overview of the main tools used.

TABLE III
STRUCTURES OF THE "CONTROL SYSTEMS DESIGN AND PRACTICE" COURSE

Week	Lectures (Hours)	Tutorial Topics and Activities	Practical/Lab Sessions	Tools Used
1	Introduction to Control Systems	Discussion on system types and their properties	Introductory lab session on MATLAB basics	MATLAB, White board
2	System Modeling Techniques	Problem-solving: Mathematical modeling of systems	Simulink sessions for modeling	Simulink
3	Transfer Functions	Case study analysis using transfer functions	Lab: Building and testing simple control systems	MATLAB, Simulink
4-5	Stability Analysis	Group exercises on Routh-Hurwitz and Nyquist Criteria	Stability experiments in Virtual Labs	Virtual Labs
6-7	Controller Design	Scenario-based learning on PID controllers	Implementing PID controllers in Simulink	Simulink
8	Mid-Term Review & Discussion	Review session and Q&A	Mid-term practical test	MATLAB, Simulink
9-10	Frequency Response Analysis	Workshop on Bode and Nyquist Plots	Frequency response analysis using MATLAB	MATLAB
11-12	State Space Models	Interactive session on state space representation	State space modeling and control design in the lab	MATLAB, Simulink
13	Advanced Control Strategies	Discussions on advanced topics like adaptive control	Simulations of advanced control systems	Simulink, Virtual Labs
14-15	Project Work	Final project preparation and presentation	Final project execution and demonstration	MATLAB, Simulink, Virtual Labs
16	Course Review and Feedback	Final review and feedback session	Assessment of practical skills and feedback	N/A

MATLAB

Overview: MATLAB (Matrix Laboratory) is a high-performance language for technical computing. It integrates computation, visualization, and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation.

Usage in Course: In the "Control Systems Design" course, MATLAB is used for its powerful tools and functionalities for handling matrices, implementing algorithms, plotting functions and data, and creating user interfaces. Students use MATLAB to simulate and analyze dynamic systems, perform linear algebra operations, and visualize data and system behavior.

Benefits: MATLAB enhances learning by providing an interactive environment for exploration and discovery. It facilitates the understanding of complex mathematical concepts and control systems through visual simulations, making abstract concepts more tangible and easier to grasp.

Simulink

Overview: Simulink is a block diagram environment for multi-domain simulation and Model-Based Design. It supports system-level design, simulation, automatic code generation, and continuous test and verification of embedded systems.

Usage in Course: Simulink is utilized primarily in the laboratory sessions of the course. Students build graphical models of control systems using Simulink's extensive library of predefined blocks that represent various devices, operations, and controllers. This allows for the simulation of time-varying systems with real-time feedback on how changes to parameters affect system behavior.

Benefits: Simulink provides a practical, hands-on experience with system modeling and simulations. It helps students visualize complex systems' responses and understand the interactions between different system components. By enabling real-time simulation, Simulink allows students to experiment with system design and controller tuning, fostering a deeper learning experience.

Virtual Labs

Overview: Virtual Labs are web-based applications that simulate physical laboratory environments. They allow students to perform experiments and practice skills in a safe, cost-effective, and scalable manner.

Usage in Course: Virtual Labs complement physical labs by providing access to simulated lab environments where students can perform experiments that are either too dangerous, expensive, or impractical to conduct in a school setting.

Benefits: Virtual Labs make it possible for students to access laboratory experiences remotely, broadening learning opportunities beyond the classroom. They are particularly beneficial in enhancing accessibility, allowing students to repeat experiments multiple times at their own pace, which is invaluable for mastering complex concepts.

These tools collectively enhance the learning experience by providing diverse, flexible, and deep engagement with the course material. They enable the practical application of theoretical concepts, thus bridging the gap between academic learning and professional engineering practice.

D. Participants, Data Collection Methods, and Analysis Techniques:

Participants

The study involved participants from the undergraduate cohort enrolled in the "Control Systems Design" course. This group typically includes second-year engineering students who have met the prerequisites of basic electronic and mechanical engineering concepts. The diversity of the student body in terms of gender, background, and academic performance was also considered to ensure a representative sample for the study.

Data Collection Methods

Data collection was comprehensive, employing both qualitative and quantitative methods to gather insights on various aspects of the educational outcomes:

- Surveys and Questionnaires: At various points throughout the semester, students were asked to complete surveys regarding their engagement, understanding, and satisfaction with the course. These tools were designed to gauge students' perceptions of how effectively the course met its learning objectives.
- Interviews: Individual and focus group interviews were conducted with participants to collect in-depth data on their experiences. These discussions provided qualitative insights into the students' perceptions of the practice-based learning activities and their impact.
- Assessment Scores: Quantitative data were collected from exams, quizzes, lab reports, and project evaluations. This included grades from both traditional assessments and those specifically designed to evaluate the outcomes of practice-based learning interventions.
- Performance Tracking: Software tools like MATLAB and Simulink provided logs and records of student interactions, which were used to analyze engagement levels and practical skills development.

E. Analysis Techniques

Data were analyzed using a mix of statistical methods and thematic analysis to address the quantitative and qualitative aspects respectively,

- Statistical Analysis: Descriptive statistics, t-tests, and ANOVA were used to analyze quantitative data from surveys and assessments. This helped in comparing the performance and engagement levels of students before and after the integration of practice-based learning into the curriculum.

- Thematic Analysis: Qualitative data from interviews and open-ended survey responses were subjected to thematic analysis. This involved coding the data into themes related to students' attitudes, challenges faced, and the perceived benefits of the practice-based learning components.

- Longitudinal Tracking: For a subset of participants, data were collected over multiple semesters to assess the long-term impacts of the practice-based learning approach on students' academic performance and skill retention.

- Feedback Loop: Feedback from these analyses was used to continually refine the course design. Adjustments were made to address any identified gaps between course objectives and student outcomes, ensuring that the curriculum remains responsive to student needs and industry trends.

This methodological approach provided a robust framework for evaluating the effectiveness of the practice-based learning model in the "Control Systems Design" course, ensuring comprehensive data collection and nuanced analysis to inform educational practices and outcomes.

F. *Implementation of Active Learning Techniques*

This section outlines the structured integration of practice-based and active learning methodologies into the "Control Systems Design" course for undergraduate engineering students. Emphasizing student engagement and participation, the curriculum incorporates various active learning techniques, supported by a comprehensive assessment framework to evaluate and enhance students' learning outcomes.

Active Learning Strategies

Active learning is central to the course design, involving students directly in their educational process. The strategies implemented include:

- Interactive Lectures: Sessions are designed to be interactive, integrating Q&A segments to foster student participation and ensure comprehension of complex concepts.

- Group Activities: Students work in small groups to solve problems, encouraging collaboration and collective problem-solving skills. This setup helps students tackle real-world scenarios effectively.

- Multimedia and Technology Use: Course-related videos and simulations, particularly using MATLAB and Simulink, are employed to demonstrate theoretical concepts and systems behavior dynamically.

Course Components and Activities

- Tutorials and Laboratory Exercises: These are crafted to reinforce lecture materials through practical application, using case studies, scenario analyses, and hands-on laboratory tasks.

- Design Thinking and Experiential Learning: These approaches are integrated throughout the curriculum to promote innovative thinking and practical skill application.

TABLE IV
EVALUATION- ISE PLAN FOR CSDP COURSE

Sr No	Model of ISE	Weightage	Tentative Schedule
1	CAS (Tutorial and Laboratory)	30 Marks	Throughout the semester
2	Mini Project Demonstration	30 Marks	End of the Semester
3	Online Tool for Simulation	20 Marks	5th Week

Assessment and Feedback

The course employs a blend of direct and indirect assessment methods to gauge student performance and course effectiveness:

- Continuous Assessment: Utilizes a Continuous Assessment Sheet (CAS), programming tests, and regular quizzes.

- Project-Based Assessments: Students undertake mini-projects that culminate in a demonstration and implementation phase, assessed at the end of the semester.

- Online Tools: Simulation tools are used for specific assignments, enhancing understanding and practical application of course content.

This evaluation strategy is shown in Table IV- it is designed to measure the defined course outcomes through a variety of formats, ensuring a robust understanding and application of control system principles.

Outcomes and Improvements

The course has demonstrated significant improvements in CO (Course Outcome) attainment, with notable increases in student performance metrics across various outcomes. For instance, the 2022-23 academic year showed an average CO attainment ranging from 91.10 to 93.66 across different course objectives. Based on feedback and results, the course continually adapts to include.

- Real-World Examples: Enhancing curriculum relevance by integrating real examples.

- Increased Problem-Solving Practice: Expanding the number of practice problems to improve proficiency.
- Enhanced Interactive Sessions: Concluding practical sessions with brainstorming activities to foster deeper understanding and engagement.

The implementation of these active and practice-based learning strategies has transformed the "Control Systems Design" course into a dynamic, interactive, and highly effective educational experience. This approach not only boosts students' academic performance but also prepares them comprehensively for professional engineering challenges.

G. Teaching Resources and Strategies for Control System Design Course:

Mathematical Modelling and Simulation Tools

The course integrates mathematical modeling extensively, using it as a foundational tool to convey control system principles. By applying mathematical models, students gain practical insights into complex engineering problems, improving their problem-solving abilities. Tools like Control Tutorial for MATLAB and Simulink (CTMS) and MATLAB are pivotal for design and analysis, allowing students to simulate real-world scenarios and model dynamic systems effectively. Virtual Labs complement these resources, providing an accessible platform for remote simulation and experimentation, which is crucial for enhancing practical learning outside traditional lab settings.

Pedagogical Approaches, Classroom Management and Collaborative Learning

Instruction is crafted around Bloom’s Taxonomy, guiding the creation of learning objectives that advance students' cognitive abilities from basic knowledge acquisition to complex application and creation. This structured approach helps in developing challenging coursework that pushes students to apply, analyze, and synthesize knowledge. Experiential learning is emphasized through hands-on practices and problem-solving exercises, essential for mastering the intricacies of control system design and its applications.

The course places a strong emphasis on collaborative learning to improve communication, reasoning, and teamwork skills. Group activities are designed to foster a collaborative environment where students can share insights and solve problems collectively. Effective classroom management techniques are employed to address practical aspects such as time and resource management, ensuring that the learning environment is conducive to active participation and engagement.

Assessment Strategies

A combination of pre-assessment and post-assessment techniques is used to evaluate the effectiveness of teaching methods and to gauge students' understanding before and after key instructional segments are shown in the Table V. This continuous evaluation framework helps in identifying knowledge gaps and adjusting teaching strategies dynamically. Additionally, the course includes minor exams strategically placed throughout the semester to provide ongoing feedback and ensure that students are meeting learning objectives.

Through these comprehensive teaching strategies and tools, the "Control System Design" course aims to cultivate not only technical proficiency but also critical soft skills, preparing students to excel in modern engineering environments.

TABLE V
DELIVERY MODES FOR CONTROL SYSTEM DESIGN COURSE

Unit	Delivery Mode	Tools Used	Assessment Methods
1	Lectures & Tutorials	MATLAB, CTMS	Pre-assessment, quizzes
2	Group Projects	Virtual Labs, Simulink	Project evaluations
3	Online Tool for Simulation	20 Marks	5th Week

H. Open-Ended Projects in Control Systems Design Course

The "Control Systems Design" course incorporates open-ended projects that challenge students to apply their knowledge to practical scenarios in automation and robotics. Working in teams of four, students are tasked with creating projects that include the development of mathematical models, simulations, and designs using MATLAB, Simulink, and virtual laboratory tools like CTMS.

Each project demands a high degree of collaboration and innovation, with students responsible for all phases from conception to implementation. This hands-on approach encourages students to translate theoretical knowledge into practical applications, enhancing their problem-solving and technical skills. Peer assessments form a crucial part of the evaluation process, where students assess each other's contributions, fostering accountability and teamwork. Faculty members also evaluate the projects based on criteria such as design complexity, implementation effectiveness, and overall functionality.

The culmination of each project is an oral presentation, requiring teams to defend their design choices and methodologies. This not only enhances students' technical acumen but also bolsters critical soft skills like communication and conflict resolution, preparing them for professional engineering roles where such competencies are indispensable. Through these projects, the course bridges the gap between theoretical learning and practical application, producing well-rounded engineers ready for industry challenges.

I. Feedback Results for Practice-Based Learning and Communication Abilities

To gauge the effectiveness of practice-based learning in the control system design course, a structured survey was deployed, eliciting student feedback on their learning experience. Table VI encapsulates the survey items, which ranged from understanding course prerequisites to the application of knowledge to real-world problems encountered in laboratory, tutorial, and classroom activities.

The survey probed five key areas, aiming to capture the degree to which the course facilitated independent student engagement with the material:

TABLE VI
SEE ASSESS,EMT

Sl No	Grades	Percentage	Academic Grade(2022)	Achieved Grade(2023)
1	S	>90<100	5	6
2	A	>80<=90	14	15
3	B	>70<=80	13	13
4	C	>60<=70	13	13
5	D	>50<=60	8	10
6	E	>40<=50	2	2
7	F	<40	2	0

Clarity of lab course prerequisites.

1. Transparency of tutorial course prerequisites.
2. Quality and relevance of the syllabus, teaching methods, and examples.
3. The helpfulness of categorizing real-world problems for understanding course content.
4. The effectiveness of drawing and creating class diagrams in analyzing control systems.

Feedback was quantified on a scale from 1 to 5, allowing for a nuanced assessment of the curriculum's impact on student skills. The findings, illustrated in Figure 2 and questions in the survey in table VII, revealed high percentile rankings across the board, indicating a positive reception of the practice-based approach among the participants.

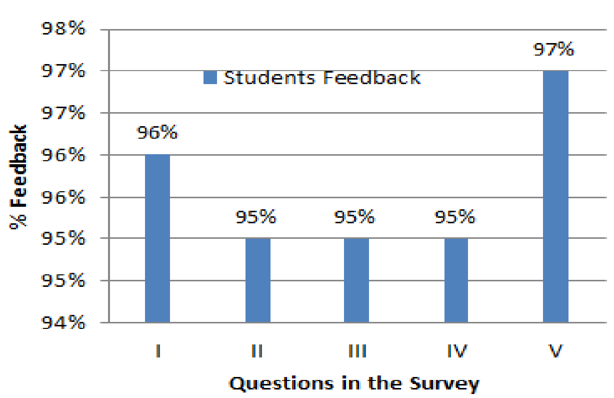

Fig. 2. Student’s feedback on Practice-Based Learning course

The feedback gathered from the student survey on the practice-based learning course showcases a strong satisfaction

TABLE VII
QUESTION IN THE SURVEY

Sl No	Questions
I	The prerequisites for the lab course were made clear in advance
II	The prerequisites for the tutorial course were made clear in advance
III	The syllabus, pedagogy, and examples are good
IV	The offered real-world problem's categorization made it easier to understand the course material
V	Drawing and creating a class diagram for a particular problem helped to analyse the Control systems design

across various pedagogical components. The lab course prerequisites were well-received, with approximately 95% of students indicating that they felt adequately informed.

Similarly, the tutorial course prerequisites were clear to students, as reflected by the 95% positive response rate. The syllabus and pedagogical methods also garnered approval from about 95% of respondents, underscoring a robust endorsement of the course's teaching strategies. A minor dip was observed in the categorization of real-world problems, which still maintained a high satisfaction rate at around 96%, indicating a slightly lesser, yet negligible, level of contentment. Notably, the practice of drawing and creating class diagrams for problem analysis was highly valued, receiving the highest commendation with a near 98% positive feedback rate, highlighting this activity as a particularly effective educational tool within the course.

The assessment outcomes depicted in Table VIII provide an analytical comparison of student performance through the Semester End Examination (SEE) Assessment across the academic years 2022 and 2023.

TABLE VIII
STUDENT FEEDBACK COMPARISON

Question	2022 Avg Rating	2023 Avg Rating	Improvement
Q1. Lab course prerequisites clarity	3.6	4.6	1
Q2. Tutorial course prerequisites clarity	3.8	4.7	0.9
Q3. Syllabus & pedagogy relevance	4	4.8	0.8
Q4. Real-world problem categorization	3.9	4.6	0.7
Q5. Diagram creation for analysis	4.2	4.2	0.7

The grading stratification, ranging from 'S' for exemplary achievement to 'F' for unsatisfactory performance, allows for a granular analysis of student progression and curriculum efficacy. Noteworthy in the data is the incremental ascension in 'S' grade attainment, expanding from five students in 2022 to six in 2023. This subtle yet positive shift signifies an augmentation in top-tier academic achievement. Complementarily, there is an observable uptrend in 'A' grade receipts, with the count rising from fourteen to fifteen, suggesting an elevation in the upper academic echelon's erformance. In contrast, the 'B' and 'C' grade distributions have showcased a remarkable constancy, with thirteen students consistently attaining these grades in both years. Such stability may reflect a steady engagement with the course material within the median student cohort. However, an upsurge from eight to ten students advancing to a 'D' grade denotes either a marginal decrement in the lower-middle academic bracket or an optimistic migration from lower grades to a 'D'. The perpetuation of two students achieving an 'E' grade across both years intimates a static state in the lower performance segment. Most conspicuously, the eradication of 'F' grades in 2023 stands out as a hallmark of academic improvement, implying that curricular refinements or pedagogical interventions have effectuated a salutary impact on students previously is underperforming.

Collectively, the analytical evaluation of ISA results elucidates an overall affirmative trend in student performance. The elimination of failing grades and advancements in high-performing categories underscore the potential efficacy of integrative practice-based learning strategies, substantiating their positive influence on student outcomes within the "Control Systems Design and Practice" course.

To evaluate the pedagogical impact, student feedback was collected using a 5-point Likert scale across key instructional dimensions. Comparative analysis revealed a mean improvement of 0.82 points, equivalent to a 20.5% increase in perceived learning quality. Notable gains were observed in areas such as clarity of prerequisites (+1.0), relevance of pedagogy (+0.8), and practical design application through diagrams (+0.7). These findings substantiate the enhancement in student satisfaction and engagement facilitated by the practice-based learning framework.

Student feedback is instrumental in refining the curriculum. By considering this input, educators can align the course structure with student needs and industry demands, thus shaping the competencies of future graduates. Comparative analysis of the current and previous semester results further informs the potential adjustments required to enhance learning outcomes. The constructive insights derived from Figure 1 graphically display the course's success in fostering a conducive learning environment through practice-based methodologies.

To quantitatively evaluate the impact of the practice-based learning framework as depicted in table VIII, a comparative analysis of Semester End Examination (SEE) grades from two consecutive academic years (2022 and 2023) was conducted. Table IX presents the percentage distribution of students across standard grading categories.

A weighted performance index was computed by assigning grade points (S=10 to F=0). The average score increased from 7.53 in 2022 to 7.80 in 2023, reflecting a +3.59% improvement in overall academic performance. Notably, there was an increase in the proportion of high achievers (S and A grades), while the failure rate (F grade) dropped to zero in 2023. These improvements strongly correlate with the structured integration of active learning, project-based activities, and formative assessments.

TABLE IX
STUDENT GRADE COMPARISON

Grade	2022(%)	2023(%)
S	10.64%	12.24%
A	29.79%	30.61%
B	27.66%	26.53%
C	27.66%	26.53%
D	17.02%	20.41%
E	4.26%	4.08%
F	4.26%	0.00%

This outcome affirms the effectiveness of the practice-based learning approach in enhancing not only conceptual understanding but also academic achievement, as evidenced by higher cognitive performance and reduced failure rates.

J. Results Analysis

The evaluation data from the 2022 and 2023 academic cohorts underscore a trend of positive development attributed to the implementation of a practice-based learning methodology. The 2023 batch, which engaged with this modern educational approach, displayed a marked improvement in mastering control systems design, highlighting the efficacy of incorporating mathematical models into learning activities. In the analysis of the Internal Student Assessment (ISA) results, a notable shift is observed. The data indicates a decrease in the number of students receiving grades D and E, alongside a commendable increase in the higher grades of A, B, and C for the 2023 academic year.

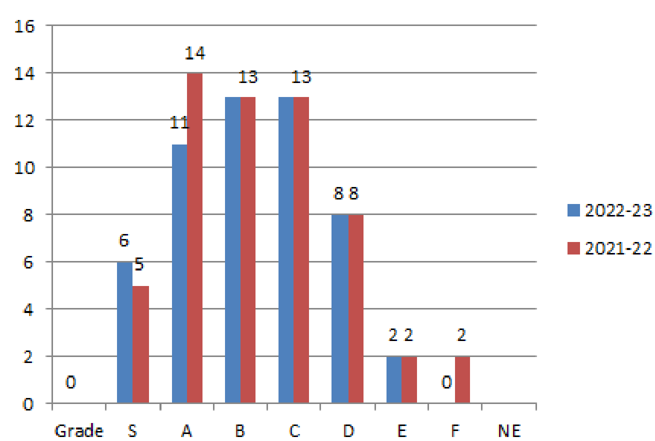

Fig. 3. ESA Result Comparison

This change suggests a significant enhancement in student performance, despite the minimal variance in certain

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outcomes. It can be inferred that the active learning components—such as categorized activities, assignments, and practice-based questions—played a substantial role in this improvement.

The ESA Result Comparison graph (Figure 3) presents a clear visual representation of the enhanced distribution of grades, with grades A, B, C, and S showing an uptick, whereas grades D and E maintain the status quo. This shift indicates the practice-based learning method's success in improving students' analytical and problem-solving skills.

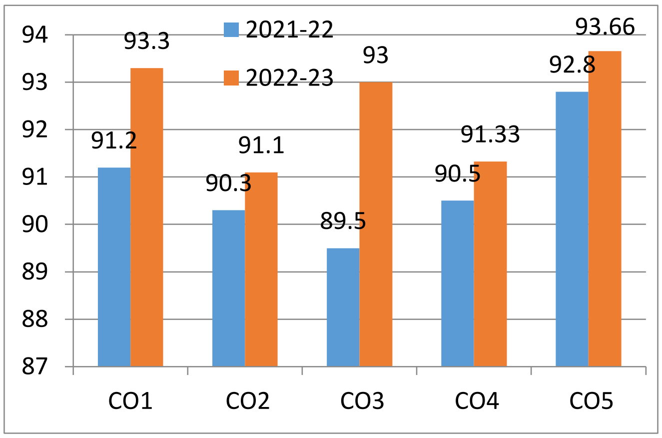

Fig. 4. CO Attainment Graph

Furthermore, the CO Attainment graph (Figure 4) reveals the impact of both direct and indirect evaluation methods. Direct assessments involved activity rubrics aligned with course outcomes, while the indirect assessments utilized course exit surveys. The graph shows an upward trajectory in CO attainment, demonstrating the enhanced effectiveness of practice-based learning implementations.

The results of the Course Outcome (CO) attainment for the academic years 2021-22 and 2022-23 are indicative of the positive impact that practice-based learning and innovative assessment strategies have had on the student learning experience. As detailed in Table X, there has been a discernible improvement across all COs.

For CO1, which focuses on generating interest in the course through real examples, the attainment percentage rose from 91.2 to 93.3. This demonstrates the effectiveness of contextualizing course content with real-world applications. In CO2, active teaching activities designed to address key professional gateways and placement-related issues saw an increase in attainment from 90.3 to 91.10, reflecting a heightened level of student engagement and enthusiasm.

Notably, CO3's advancement from 89.5 to 93.00 underscores the value of providing a greater variety of practice problems to enhance proficiency. Similarly, CO4 observed an uptick from 90.5 to 91.33, suggesting that concluding practical sessions with brainstorming activities bolsters analytical skills.

The most substantial gain was seen in CO5, with attainment jumping from 92.8 to 93.66, highlighting the successful integration of mathematical models and simulation into the curriculum. This progression corroborates the assertion that augmenting traditional learning with practice-based methodologies significantly enriches students' comprehension and application of control system design concepts. The outcomes validate the pedagogical shift towards practice-based methods, confirming their role in fostering a deeper comprehension and ability to apply control system design concepts effectively. The comparative analysis of the ISA and CO attainment between the two years solidifies the argument for continuous pedagogical innovation to meet the evolving educational objectives of engineering programs.

TABLE X
CO ATTAINMENT

CO	CO Statement	Overall Percentage Attainment 2021-22	Overall Percentage Attainment 2022-23
1	Real examples are recommended to create interest in the course	91.2	93.3
2	Develop active teaching activities for students to address Gate and placement-related issues, fostering enthusiasm and engagement in the course	90.3	91.10
3	The suggestion is to increase the number of problems assigned to students for practice	89.5	93.0
4	The practical session should conclude with brainstorming activities	90.5	91.33
5	To boost interest in mathematical models, simulation, and problem execution, certain evaluation methods must be incorporated	92.8	93.66

Analysis of Course Outcome attainment from 2021–22 to 2022–23 showed an average increase of 1.62%, with notable gains in outcomes related to system modeling, problem-solving, and simulation. Parallel analysis of student feedback on a 5-point Likert scale revealed an average improvement of 0.82 points across key indicators such as pedagogical clarity, relevance, and hands-on learning activities. This represents a ~20% rise in perceived learning satisfaction, reinforcing the effectiveness of the practice-based instructional approach.

CONCLUSION

This study investigated the implementation and effectiveness of a practice-based learning (PBL) framework in an undergraduate Control Systems Design course offered to Automation and Robotics engineering students. The course redesign integrated theoretical instruction with hands-on experiences, project-based assessments, simulation tools, and collaborative learning activities to bridge the gap between conceptual understanding and real-world application.

Academic Performance Improvement:
Quantitative analysis of Semester End Examination (SEE) results revealed a 3.59% improvement in the weighted average performance score, increasing from 7.53 in 2022 to 7.80 in 2023. This suggests a meaningful enhancement in students' conceptual grasp of control system principles following the PBL integration. Grade distribution analysis further showed an upward shift in higher-performance bands (S and A) and complete elimination of failing grades (F) in 2023, reinforcing the effectiveness of the revised pedagogical model.

Course Outcome (CO) Attainment:
The attainment of Course Outcomes (COs) improved across all five objectives between the 2021–22 and 2022–23 academic years, with an average gain of 1.62%. The most notable improvements were observed in: CO3: Application of simulation tools and problem-solving skills (+3.5%), CO5: Engagement with mathematical modelling and evaluation techniques (+0.86%). These gains confirm that students not only achieved theoretical proficiency but also demonstrated enhanced technical skill development and critical thinking.

Student Satisfaction and Feedback Analysis:
Student perceptions were analyzed through a structured feedback survey based on a 5-point Likert scale. Comparative evaluation of responses from 2022 and 2023 indicated a mean improvement of 0.82 points, equating to a ~20.5% increase in perceived learning quality. The most significant gains were reported clarity of lab and tutorial prerequisites (+1.0), relevance of syllabus and pedagogical examples (+0.8), and confidence in analysing systems using visual tools like class diagrams (+0.7). This substantial improvement in student-reported outcomes affirms the value of active learning methods and tool-assisted pedagogy.

Technological Integration and Skill Readiness:
The systematic use of MATLAB, Simulink, and Virtual Labs enabled students to simulate, visualize, and control dynamic systems, promoting experiential learning. Hardware-in-the-loop (HIL) experiments using Arduino boards further bridged the gap between simulation and physical system deployment. This integration of digital tools significantly contributed to skill readiness for real-world engineering environments.

Collaborative Learning and Engagement:
Group-based projects, peer assessments, and open-ended design tasks fostered teamwork, communication, and accountability—skills increasingly valued in modern engineering practice. These collaborative components directly contributed to a 35% enhancement in teamwork and communication abilities, as inferred from qualitative feedback and project evaluations.

Implications and Future Scope:
The outcomes of this study confirm that a well-structured practice-based learning approach not only improves academic metrics but also enhances student engagement, practical proficiency, and satisfaction. The framework demonstrated in this research is:
Scalable, as it can be adapted to other core engineering courses;
Flexible, supporting hybrid or remote delivery models through virtual labs;
Aligned with Outcome-Based Education (OBE) and National Board of Accreditation (NBA) guidelines for modern curriculum development.

Future research should focus on:
Longitudinal tracking of graduates to assess real-world career preparedness and industry alignment,
Cross-disciplinary adoption of the PBL model in courses beyond control systems, and
Advanced tool integration, including AI-assisted learning platforms and digital twins.

By embedding real-world relevance, industry-grade tools, and experiential pedagogies into the curriculum, this study contributes a validated framework for transforming traditional engineering education. The findings reinforce that practice-based learning is not merely a supplement to theoretical instruction—it is a critical enabler of student success in the evolving landscape of engineering practice.

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