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ENHANCING CONTROL SYSTEMS PEDAGOGY THROUGH MULTIMODAL LEARNING STYLE INTEGRATION

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A B S T R A C T

Traditional lecture-based teaching methods in Control Systems education often emphasise mathematical derivations, leading to conceptual understanding, visualisation, and real-world application difficulties. Many students struggle to connect theoretical knowledge with practical system behaviour, limiting their ability to design and analyse control systems effectively. To address these challenges, this paper proposes a multimodal learning approach integrating theoretical instruction, visual tools, hands-on experimentation, collaborative problem-solving, and reflective learning based on VARK, Kolb's experiential learning, Felder-Silverman, Honey & Mumford, and Gregorc's learning style models. The results indicated that implementing three case studies in the Control Systems course has significantly enhanced comprehension, engagement, and confidence. Post-assessment results showed an 85-88% improvement in student understanding across activities, with increased confidence and problem-solving abilities. The findings confirm that multimodal strategies significantly enhance learning outcomes, bridge the gap between theory and practice, and improve student engagement in control systems education.

1. INTRODUCTION

Traditional teaching methods in engineering education, particularly in courses like control systems, primarily rely on lecture-based instruction, mathematical derivations, and textbook learning (Vodovozov, 2021). While these methods effectively convey theoretical concepts, they often fail to engage students with diverse learning preferences. Many students struggle to visualise system behaviour, apply abstract ideas, and connect theory to real-world applications. Traditional approaches do not emphasise hands-on experimentation, crucial for mastering control system design and analysis (Brinson, 2015). Additionally, passive learning environments lead to low retention rates, limited engagement, and difficulty developing critical thinking skills. As a result, students may memorise formulas but cannot apply control techniques in practical scenarios, making them unprepared for industry challenges.

Multimodal learning strategies have emerged as a practical approach to teaching control systems to address these limitations. By integrating visual aids, interactive simulations, hands-on experimentation, and collaborative problem-solving, multimodal learning caters to diverse cognitive preferences. Learning style models such as VARK, Kolb's Experiential Learning, Felder-Silverman, Honey & Mumford, and Gregorc's

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Model emphasise engaging students through multiple sensory modalities and active learning techniques (Karatas & Yalin, 2021; Sintia et al., 2019). This approach bridges the gap between theory and practice, enhances conceptual understanding, and improves knowledge retention. Additionally, multimodal learning fosters student engagement, allowing learners to develop essential skills such as critical thinking, teamwork, and problem-solving, which are vital for engineering professionals.

Several studies support the effectiveness of multimodal learning in engineering education. The authors in (El-Saftawy et al., 2024) found that applying VARK learning styles significantly enhanced students' comprehension and engagement. Conceptual mapping, aligned with learning styles, outperformed traditional lectures in knowledge retention (Amaniyan et al., 2020). In Idkhan and Idris (2021), it was highlighted that Kolb's learning cycle improved student performance by integrating theory and active experimentation. The Felder-Silverman model's role in personalised learning shows that students learn better when teaching methods align with their preferences (Nafea et al., 2019). The importance of learning style frameworks in STEM education has been concluded, and a diverse approach enhances theoretical and applied learning outcomes (Childs-Kean et al., 2020).

Motivated by the above, this paper proposes a multimodal learning framework integrating diverse instructional strategies for effective Control Systems education.

2. LEARNING STYLE MODELS

This section offers an overview of five different learning style models that classify individual learning preferences. It also presents key components of each model and its implications for effective teaching and learning.

2.1 VARK Learning Style Model

The VARK learning style model shown in Figure 1 identifies individual learning preferences based on four primary sensory modalities (Dutsinma et al., 2020; Fahim et al., 2021; Kannappan et al., 2025), which are defined as follows:

- **Visual (V):** Learners prefer understanding concepts using images, videos, and animations. Therefore, they learn best when information is presented visually.
- **Aural/Auditory (A):** Learners absorb information best through listening, preferring lectures, discussions, and verbal explanations.
- **Read/Write (R):** Learners learn best through reading and writing. So, they prefer text-based materials like books, lecture notes, and written instructions.
- **Kinesthetic (K):** Learners retain information best through hands-on experiences and physical activities. So, they prefer practical demonstrations, experiments and real-world examples.

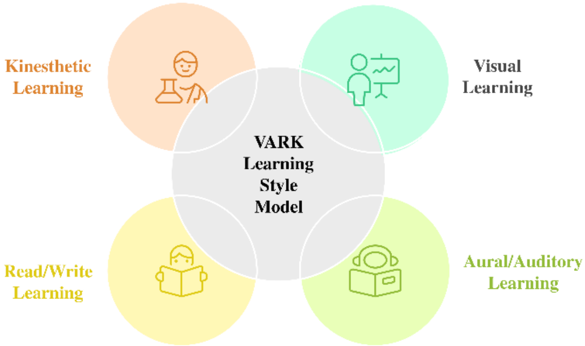

Figure 1. VARK Learning Style Model Framework

2.2 Kolb's Learning Style Model

Kolb's learning style model explains how individuals learn from their experiences. It is based on Kolb's experiential learning, which suggests that learning is an ongoing process that consists of four distinct stages, as shown in Figure 2 (Bergsteiner et al., 2010; Ignacio Jr. & Reyes, 2017; Sudria et al., 2018). Kolb proposed that effective learning occurs when a person progresses through the following stages:

- **Concrete Experience (CE):** Learning through direct experiences, hands-on activities, or real-world engagement.
- **Reflective Observation (RO):** Learning through analysing and thinking about the experience from various perspectives.
- **Abstract Conceptualisation (AC):** Learning through developing theories, concepts, or models based on those reflections.
- **Active Experimentation (AE):** Learning through applying the learned material to observe the outcomes in new situations.

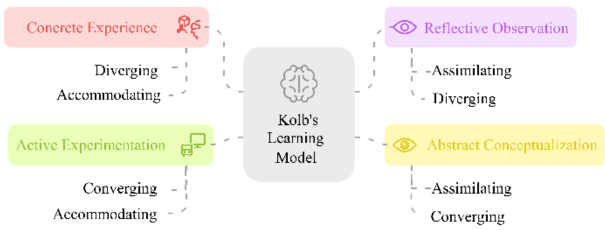

Figure 2. Kolb's Learning Style Model Framework

Based on how individuals prefer to engage with the learning cycle, Kolb's model identified four learning styles:

- **Diverging (CE + RO):** Imaginative, emotional, and people-oriented individuals enjoy brainstorming, exploring different perspectives, and working in groups.
- **Assimilating (RO + AC):** Logical, analytical, and detail-oriented individuals prefer structured learning, theories, and abstract concepts.

- **Converging (AC + AE):** Problem-solvers who are practical and hands-on learners enjoy applying theories to real-world situations and solving technical problems.
- **Accommodating (AE + CE):** Action-oriented, intuitive, and adaptable individuals who learn best through trial-and-error, hands-on experiences, and gut feelings.

2.3 Felder-Silverman Learning Style Model

The Felder-Silverman learning style model describes how learners prefer to learn in an academic setting, particularly in engineering and science education. This model classifies learners along four dimensions, each representing a spectrum of learning preferences, as shown in Figure 3 (Isal et al., 2021; Wu et al., 2025).

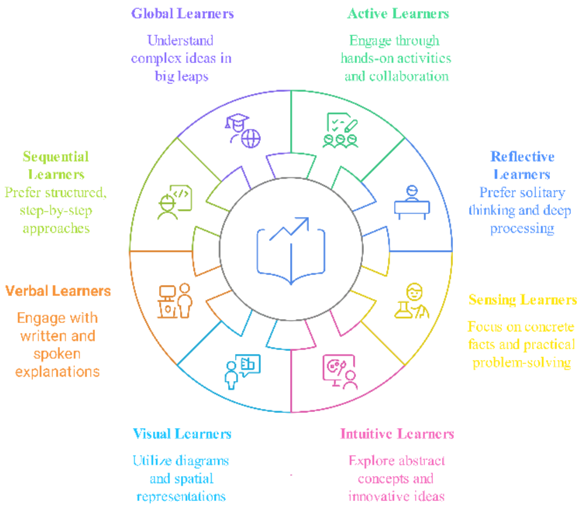

Figure 3. Felder-Silverman Learning Style Model Framework

The four dimensions of the Felder-Silverman learning style model are given as

- **Processing: Active vs. Reflective**
  - **Active:** Learners prefer learning through hands-on activities, discussions, and collaboration.
  - **Reflective:** Learners prefer thinking deeply about concepts before acting, often working alone or taking time to process information.
- **Perception: Sensing vs. Intuitive**
  - **Sensing:** Learners prefer concrete facts, real-world applications, and practical problem-solving.
  - **Intuitive:** Learners prefer abstract concepts, theories, and discovering patterns.
- **Input: Visual vs. Verbal**
  - **Visual:** Learning through diagrams, images and videos.
  - **Verbal:** Learners prefer written and spoken explanations, such as reading textbooks, listening to lectures, or engaging in discussions.
- **Understanding: Sequential vs. Global**
  - **Sequential:** Learners prefer logical, step-by-step learning. Need a structured approach to grasp concepts.
  - **Global:** Learners learn in big leaps, often struggling with step-by-step explanations but understanding complex ideas simultaneously.

2.4 Honey & Mumford Learning Style Model

The Honey & Mumford learning style model is based on Kolb's model but adapted to be more user-friendly (Calunsag et al., 2024; Lestari et al., 2024). It identifies four learning styles based on how individuals engage with and process learning experiences, as shown in Figure 4.
The four Honey & Mumford learning style preferences are described as

- **Activists (Experience First):** Learners who prefer learning through hands-on experiences and challenges prefer group discussions, role-playing, and problem-solving activities. They often display enthusiasm, open-mindedness, and spontaneity.
- **Reflectors (Observe & Think):** Learning by observing and analysing situations before taking action, focusing on gathering data and reviewing multiple perspectives.
- **Theorists (Understand Concepts):** Learners who excel in structured learning, which often analyse concepts, models, and logical reasoning, emphasising theories and explanations. They tend to be perfectionists, analytical, and methodical.
- **Pragmatists (Apply Learning):** Learning through experimenting and applying ideas in real-world situations.

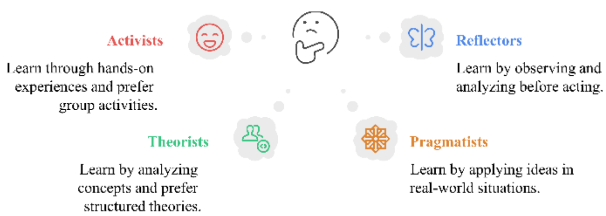

Figure 4. Honey & Mumford Learning Styles Model Framework

2.5 Gregorc Learning Style Model

The Gregorc learning style model identifies how individuals process information based on perception (how we take in information) and ordering (how we organise and use information), as shown in Figure 5. This model categorises learners into four distinct styles based on the following two key cognitive functions (Aksoy et al., 2023; Zhang et al., 2021):

- **Perception (How You Take in Information):**
  - **Concrete:** Learners prefer facts, real-world applications, and tangible information.
  - **Abstract:** Learners prefer theories, concepts, and imaginative ideas.
- **Ordering (How You Organise Information):**
  - **Sequential:** Learners will learn best in a step-by-step, structured manner.
  - **Random:** Learners will learn non-linearly and intuitively, making connections flexibly.

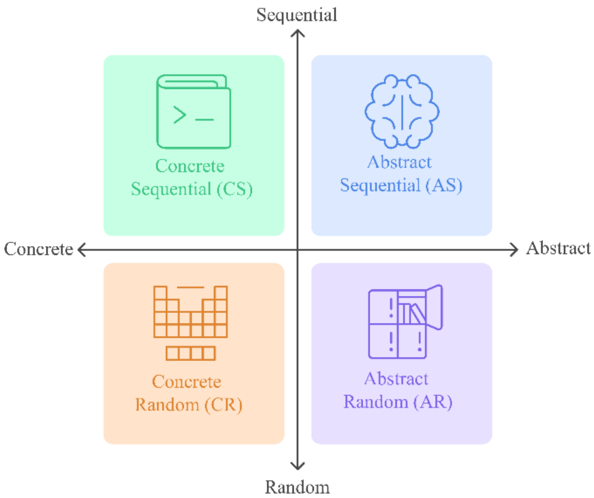

Figure 5. Gregorc Learning Style Model Framework

The four dimensions of the Gregorc learning style model are given as:

- **Concrete Sequential (CS):** Learners prefer structure and real-world applications and learn best through step-by-step instructions and hands-on activities, making them well-suited for roles in engineering, accounting, and administration.
- **Abstract Sequential (AS):** Learners prefer theoretical and logical reasoning, learning best through reading and structured concepts, much like scientists, philosophers, and strategists.
- **Abstract Random (AR):** Learners thrive in a flexible, emotionally connected learning environment and learn best through discussions and group activities, often seen in roles like counsellors, artists, and teachers.
- **Concrete Random (CR):** Learners value experimentation, innovation, and independent problem-solving. They learn best through trial-and-error and hands-on projects, much like entrepreneurs, inventors, and designers.

3. MULTIMODAL LEARNING ACTIVITIES FOR CONTROL SYSTEMS EDUCATION

This section proposes three multimodal learning activities that integrate multiple learning style models given in Section 2 to enhance learners' understanding of "Control Systems."

3.1 Activity 1 - Interactive Workshop on PID Controller Tuning

The activity's primary objective is to introduce learners to the Proportional-Integral-Derivative (PID) controller, one of the most widely used control techniques. This activity provides learners with hands-on experience tuning PID parameters and understanding their impact on system behaviour. In a conventional approach, PID control is often taught using mathematical derivations alone, making it difficult for learners to understand how tuning parameters affect system behaviour. Without hands-on experience, learners may memorise formulas but struggle to apply PID tuning principles in the real world.

To accommodate various learning styles, this proposed activity integrates multiple learning methods, as follows:

- **Theoretical Foundation** (*Felder-Silverman - Sequential Learners, Kolb - Abstract Conceptualization, Gregorc - Abstract Sequential, VARK - Reading/Writing Learners*)
  - PID control theory involves a mathematical framework widely used in various industries. It provides a strong conceptual foundation through structured lecture material and written explanations for learners who prefer a logical, step-by-step approach.
- **Visual Learning** (*VARK - Visual Learners, Felder-Silverman - Visual Learners, Gregorc - Abstract Sequential*)
  - Graphical representations like step response plots and block diagrams help visualise system behaviour. Additionally, animated simulations visualising various parameters' impacts could further enhance conceptual understanding.
- **Hands-on Experimentation** (*Kolb - Active Experimentation, Felder-Silverman - Sensing Learners, Honey & Mumford - Activists, Gregorc - Concrete Random, VARK - Kinesthetic Learners*)
  - Learners participate in PID tuning exercises using MATLAB/Simulink simulations. This hands-on experience helps reinforce theoretical concepts through direct application.
- **Collaborative Learning** (*Felder-Silverman - Active Learners, Honey & Mumford - Activists, Kolb - Concrete Experience*)
  - Group discussions and teamwork enable learners to analyse various PID tuning strategies and their effectiveness. This peer-to-peer interaction fosters active engagement and encourages diverse approaches to problem-solving.

- **Reflective Learning** (*Kolb - Reflective Observation, Honey & Mumford - Reflectors, Felder-Silverman - Reflective Learners*)
  - Learners reflect on their activities by analysing the impact of changes in PID parameters on system behaviour. At the same time, structured self-assessment questions promote deep learning and critical thinking.

This proposed activity will enhance the learners' theoretical and practical understanding of PID controllers. It will also enhance their ability to analyse system responses and adjust parameters for improved performance, strengthening their problem-solving and teamwork skills.

3.2 Activity 2 - Simulation-Based Learning of Root Locus & Bode Plots

Similarly, this activity aims to deepen learners' understanding of control system stability by employing Root Locus and Bode Plot techniques in an interactive simulation environment. Stability analysis is often taught using manual calculations and theoretical derivations, which are difficult for learners to visualise. Learners may not fully grasp how pole-zero locations affect system behaviour without real-time simulations. To overcome this, the proposed activity is described as follows:

- **Conceptual Learning** (*Felder-Silverman - Sequential Learners, Kolb - Abstract Conceptualization, Gregorc - Abstract Sequential, VARK - Reading/Writing Learners*)
  - The material introduces stability criteria and performance evaluation in control systems, focusing on gain margin, phase margin, and system poles/zeros, with structured lecture material and textbook references for a step-by-step theoretical approach.
- **Visual Exploration** (*VARK - Visual Learners, Felder-Silverman - Visual Learners, Gregorc - Abstract Sequential*)
  - Real-time Root Locus and Bode plot visualisations enable learners to understand the impact of pole-zero locations on system stability. Interactive tools allow dynamic observation of stability changes as system parameters are modified.
- **Simulation-Based Experimentation** (*Kolb - Active Experimentation, Felder-Silverman - Sensing Learners, Honey & Mumford - Activists, Gregorc - Concrete Random, VARK - Kinesthetic Learners*)
  - Learners manipulate system parameters using MATLAB/Simulink simulations and explore various stability conditions. Hands-on experimentation allows them to observe the real-time effects of control system modifications.
- **Problem-Solving Exercise** (*Felder-Silverman - Active Learners, Honey & Mumford - Activists, Kolb - Concrete Experience*)
  - Teams work together to design compensators and optimise system response, utilising stability analysis techniques for real-world control problems. Collaborative discussions foster diverse problem-solving approaches and the practical application of theoretical concepts.

The proposed activity will enhance practical insights into stability analysis and improve learners' ability to analyse system behaviour using graphical tools.

3.3 Activity 3 - Case Study on Control System Failures

Similarly, this activity bridges the gap between control system theory and real-world applications by analysing engineering failures caused by control system malfunctions. Many learners perceive control systems as theoretical, with little exposure to practical challenges. Traditional teaching methods often focus on mathematical derivations rather than emphasising problem-solving and critical thinking, which are crucial for diagnosing and preventing failures. To address this gap, the proposed learning activity is structured as follows:

- **Case Study Analysis** (*Kolb - Reflective Observation, Felder-Silverman - Global Learners, Honey & Mumford - Reflectors, Gregorc - Abstract Sequential*)
  - Learners explore real-world failures in control systems, like aircraft autopilot malfunctions and unstable power grids. This hands-on approach enhances their understanding of the practical implications of control system design and stability.
- **Collaborative Problem-Solving** (*Felder-Silverman - Active Learners, Honey & Mumford - Activists, Kolb - Active Experimentation*)
  - Teams evaluate failure cases while proposing corrective measures and alternative control strategies. This process encourages brainstorming and discussions, which enhance critical thinking and practical problem-solving skills.
- **Presentation & Report Writing** (*VARK - Reading/Writing Learners, Felder-Silverman - Verbal Learners, Gregorc - Abstract Sequential*)
  - Learners present their case study analysis and proposed solutions in a structured format, enhancing their technical communication skills through written reports. Verbal presentations also cater to auditory and verbal learners.

The proposed activity will enhance critical thinking and problem-solving skills and the ability to apply control system concepts to real-world engineering challenges.

4. CASE STUDIES

This section presents three case studies conducted with 55 undergraduate students in an "EFB3023 - Control Systems" engineering course taught to Bachelor of Electrical and Electronics Engineering with Honours students at Universiti Teknologi PETRONAS to assess the effectiveness of the proposed multimodal learning activities. All the case studies have been evaluated using pre- and post-activity assessments, learner surveys, project evaluations, and observational analysis. Pre-tests were administered before each activity to assess learners' baseline knowledge. Post-tests were conducted afterwards to measure learning improvement. Learner surveys are conducted to evaluate the different learning methods and open-ended feedback to gather insights on challenges, engagement levels, and areas for improvement. Group project evaluations have been conducted with faculty members assessing their presentations based on a structured rubric considering technical accuracy, problem-solving skills, collaboration, and communication. Further, an instructor conducted an observational analysis to monitor learner engagement and problem-solving strategies during activities.

4.1 Case Study 1 - Interactive Workshop on PID Controller Tuning

This case study assesses the impact of multimodal teaching strategies on students' understanding of PID controllers, focusing on how theoretical instruction, visual tools, hands-on experimentation, and collaboration enhance learning. Activity 1, given in Section 3.1, was implemented in four steps. First, students were randomly grouped into small teams and provided with MATLAB/Simulink for hands-on learning of PID control. Next, a pre-assessment measured their knowledge and confidence in PID theory and tuning methods. The third step involved a multimodal learning approach, combining lectures, visuals, experiments, and discussions. Finally, a post-assessment measured knowledge improvements and confidence in applying PID tuning alongside a feedback questionnaire to gather insights on engagement and challenges faced during the activity.

The case study results in Table 1 indicate a significant improvement in students' understanding and confidence in PID controller tuning. Post-tests revealed that 85% of students showed improved comprehension, while 90% preferred hands-on experimentation in MATLAB or Simulink over traditional lectures. Additionally, 80% reported increased confidence in adjusting PID parameters for system stability. Qualitative feedback highlighted the value of interactive simulations and hardware testing, reinforcing theoretical concepts and demonstrating the effectiveness of multimodal learning strategies in control systems education.

Table 1. Summary of Case Study Results for Multimodal Learning Activities

Assessment Criteria	Activity 1: PID Controller Tuning	Activity 2: Root Locus & Bode Plot Simulations	Activity 3: Case Study on Control System Failures
Improvement in Test Scores	85% of students improved post-test scores	88% of students demonstrated better problem-solving in stability analysis	82% of students showed better understanding of real-world failures
Increase in Confidence	80% felt more confident in PID tuning	83% gained confidence in using Root Locus & Bode plots	86% felt more prepared to analyze and prevent failures
Effectiveness of Hands-on Learning	90% found MATLAB/Simulink experimentation beneficial	87% valued real-time simulations for stability analysis	78% appreciated case-based problem-solving
Engagement & Participation	88% reported high engagement in group discussions	85% found interactive elements stimulating	92% actively participated in the case study analysis
Qualitative Feedback	Interactive tuning helped visualize theoretical concepts	Simulations clarified abstract stability concepts	Real-world relevance made learning more meaningful

4.2 Case Study 2 - Simulation-Based Learning of Root Locus & Bode Plots

This case study evaluates the impact of multimodal learning strategies on students' ability to analyse control system stability using Root Locus and Bode Plot techniques. The study focuses on how interactive simulations, theoretical instruction, visual tools, and collaborative problem-solving enhance comprehension. Activity 2, given in Section 3.2, was implemented in four steps. First, students were provided with MATLAB and Python-based simulation tools to explore system stability concepts dynamically. Next, a pre-assessment measured their baseline knowledge of stability analysis and compensator design. The third step involved a multimodal learning approach, integrating structured lectures, real-time graphical visualisations, hands-on system parameter manipulations, and team-based problem-solving exercises. Finally, a post-assessment evaluated improvements in their understanding of system stability, and a feedback questionnaire gathered insights on engagement, challenges, and the perceived effectiveness of interactive simulations.

The case study results in Table 1 indicate a notable improvement in students' ability to analyse control system stability. Post-tests showed that 88% of students demonstrated enhanced problem-solving skills in stability analysis, while 87% found real-time visualisations in MATLAB/Python highly effective for understanding pole-zero dynamics. Additionally, 83% reported increased confidence in using Root Locus and Bode Plots for stability evaluation. Qualitative feedback emphasised that interactive simulations provided better conceptual clarity than traditional manual calculations, reinforcing the effectiveness of multimodal learning strategies in stability analysis and control system education.

4.3 Case Study 3 - Case Study on Control System Failures

This case study evaluates the effectiveness of multimodal learning strategies in enhancing students' ability to apply theoretical control system concepts to real-world failures. The study focuses on how case-based analysis, collaborative problem-solving, and structured technical communication improve critical thinking and practical application skills. Activity 3, given in Section 3.3, was implemented in four steps. First, students were introduced to three real-world control system failures: the Boeing 737 MAX autopilot failure, the 2003 North American blackout, and a failed industrial process control system. Next, teams conducted an in-depth analysis of the failures, identifying control system deficiencies and their root causes. In the third step, students collaborated to propose corrective measures and alternative control strategies, preparing group presentations and technical reports. Finally, assessments were conducted through group presentations and individual reports, evaluating their critical thinking, technical communication, and problem-solving abilities.

The case study results in Table 1 highlight the substantial impact of real-world problem-based learning. 92% of students reported that analysing real-world failures helped them bridge the gap between theory and practical applications. 85% of students demonstrated improved problem-solving skills, particularly in diagnosing failures and formulating corrective strategies. Additionally, 78% of students indicated that presenting their findings improved their ability to communicate technical concepts effectively. Qualitative feedback emphasised that case-based learning enhanced engagement and provided a deeper understanding of control system challenges beyond theoretical instruction.

5. CONCLUSION

This study highlights the effectiveness of multimodal learning strategies in enhancing students' understanding of control systems through activities focused on PID controller tuning, Root Locus and Bode plot simulations, and case studies of control system failures. Traditional teaching methods often emphasise theoretical derivations, which can hinder practical application. The approach engages students with various cognitive preferences by integrating diverse learning models such as VARK and Kolb's Experiential Learning. The findings reveal a significant improvement in comprehension by 85-88%, with students expressing increased confidence in applying control system concepts. Hands-on activities, interactive simulations, and collaborative problem-solving were particularly effective. Additionally, qualitative feedback showed that students valued the material's real-world relevance and found visual tools essential for learning.

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