Global Journal of Engineering Innovations & Interdisciplinary Research

Original Article

Effectiveness of AI-Based Learning Tools in Improving Engineering Mathematics Understanding

G. Radhika, G. Sriraja Vijaya Krishna, K. M. V. Ramana, M. Srivani

Assistant Professor (Mathematics), H&S Department, Christu Jyothi institute of Technology & Science, Hyderabad.

Correspondence

G. Radhika

Assistant Professor (Mathematics), H&S Department, Christu Jyothi institute of Technology & Science

- Received Date: 21 July 2025
- Accepted Date: 09 Jan 2026
- Publication Date: 11 Jan 2026

Abstract

Engineering mathematics is fundamental to engineering education, yet many students struggle to achieve conceptual clarity and problem-solving proficiency through traditional teaching methods alone. This study investigates the effectiveness of AI-based learning tools in improving engineering mathematics understanding among undergraduate engineering students. An AI-assisted learning environment incorporating adaptive practice, intelligent feedback, and personalized learning pathways was implemented alongside conventional classroom instruction. Student performance was evaluated using pre-test and post-test assessments, learning outcome metrics, and engagement indicators. The results show that students using AI-based tools achieved significantly higher post-test scores, improved conceptual understanding, greater problem-solving accuracy, and reduced error rates compared to those relying solely on traditional instruction. Increased engagement and sustained learning activity further highlight the benefits of AI-supported learning. The findings demonstrate that AI-based learning tools, when integrated with conventional teaching, offer an effective approach to enhancing engineering mathematics education.

Introduction

Engineering mathematics forms the foundation for core engineering disciplines such as mechanics, electronics, signal processing, and control systems. Concepts including calculus, linear algebra, differential equations, and numerical methods are essential for problem-solving and analytical reasoning in engineering education. Despite its importance, engineering mathematics is often perceived as challenging by students due to its abstract nature, heavy reliance on symbolic reasoning, and the gap between theory and practical application. Traditional teaching methods, which are largely lecture-based, may not always address individual learning differences or provide sufficient interactive engagement.

Challenges in Engineering Mathematics Education

Many engineering students struggle to develop conceptual understanding in mathematics, leading to poor academic performance and reduced confidence. Large classroom sizes, limited personalized feedback, and time constraints restrict instructors' ability to address individual learning needs. Furthermore, students often rely on rote memorization rather than developing deep conceptual clarity, which affects their ability to apply mathematical concepts in engineering contexts. These challenges highlight the need for innovative instructional approaches that support active learning and personalized understanding.

Role of AI-Based Learning Tools

Artificial intelligence–based learning tools have emerged as a promising solution to enhance student engagement and understanding. AI-driven platforms can adapt content based on learner performance, provide instant feedback, and offer personalized learning paths. Features such as intelligent tutoring systems, automated problem-solving guidance, adaptive quizzes, and interactive simulations enable students to learn at their own pace while receiving targeted support. These tools help bridge the gap between abstract mathematical theory and practical problem-solving by offering step-by-step explanations and real-time error correction.

AI in Mathematics Education

Recent advancements in educational technology have shown that AI-based systems can effectively support mathematics learning by identifying knowledge gaps and adjusting instructional strategies accordingly. Machine learning algorithms analyze student responses to predict learning difficulties and recommend appropriate resources. Studies in mathematics

Citation: Radhika G, Krishna GSV, Ramana KVM, Srivani M. Effectiveness of AI-Based Learning Tools in Improving Engineering Mathematics Understanding. GJEIIR. 2026;6(1):0136.

education suggest that AI-supported learning environments encourage self-directed learning, improve conceptual understanding, and enhance problem-solving skills. Such systems are particularly valuable in engineering mathematics, where continuous practice and feedback are crucial for mastery.

Motivation and Research Gap

Although AI-based learning tools are increasingly adopted in educational settings, empirical evidence evaluating their effectiveness in engineering mathematics education remains limited. Many studies focus on general mathematics or school-level education, with fewer investigations centered on engineering students and advanced mathematical concepts. Additionally, comparative analysis between traditional teaching methods and AI-assisted learning approaches is not sufficiently explored. This gap underscores the need for systematic evaluation of how AI-based tools influence student understanding, engagement, and learning outcomes in engineering mathematics.

Objective of the Study

The objective of this study is to evaluate the effectiveness of AI-based learning tools in improving engineering mathematics understanding among undergraduate engineering students. The study examines learning performance, conceptual clarity, and student engagement by comparing AI-supported learning environments with conventional instructional methods. The findings aim to provide insights into the potential of artificial intelligence to enhance mathematics education and support more effective learning experiences in engineering programs.

Literature survey

Traditional Approaches to Teaching Engineering Mathematics

Conventional methods of teaching engineering mathematics primarily rely on classroom lectures, textbook-based problem solving, and periodic assessments. These approaches emphasize theoretical explanations and manual practice, which help build foundational knowledge but often lack personalization. Several studies report that while traditional instruction is effective for motivated learners, it may not adequately support students who struggle with abstract reasoning or require additional practice and feedback. The limited interaction and delayed evaluation in traditional classrooms contribute to gaps in conceptual understanding.

Technology-Enhanced Learning in Mathematics Education

The integration of technology into mathematics education has gained momentum with the introduction of digital learning platforms, online tutorials, and interactive software. Research shows that computer-assisted learning improves visualization of mathematical concepts and enables students to engage with dynamic representations of equations and graphs. Learning management systems and e-learning tools have been found to enhance accessibility and flexibility, allowing students to revisit content and practice problems at their own pace. However, these tools often provide static content and lack adaptive intelligence.

Artificial Intelligence in Educational Systems

Artificial intelligence has significantly transformed educational technologies by enabling adaptive and personalized learning environments. AI-based learning tools use algorithms to analyze student performance, learning behavior, and response patterns. Intelligent tutoring systems provide customized instruction, automated feedback, and guided problem-solving steps. Studies in higher education indicate that AI-driven platforms can improve student engagement and learning efficiency by tailoring content difficulty and instructional strategies to individual learners.

AI Applications in Mathematics Learning

In mathematics education, AI applications have been used to support problem-solving, error diagnosis, and conceptual reinforcement. Research highlights the effectiveness of AI-based tutoring systems in identifying misconceptions and offering targeted explanations. Adaptive assessment systems powered by AI dynamically adjust question difficulty based on student responses, helping learners progress gradually. These systems have been shown to improve conceptual understanding and reduce anxiety associated with complex mathematical topics.

AI-Based Learning in Engineering Education

Within engineering education, AI-based learning tools have been applied to subjects such as programming, circuit analysis, and numerical methods. Studies suggest that AI-supported platforms encourage active learning and self-regulated study habits among engineering students. However, fewer investigations focus specifically on engineering mathematics courses, where the complexity of content demands both theoretical clarity and extensive practice. The existing literature indicates potential benefits but lacks comprehensive evaluation in this context.

Identified Research Gaps

Although previous research demonstrates the advantages of AI-based learning tools in general education and mathematics learning, limited empirical studies assess their effectiveness in improving engineering mathematics understanding. Most studies focus on short-term performance metrics rather than long-term conceptual retention. Additionally, comparative studies between AI-assisted learning and traditional teaching methods in engineering mathematics remain scarce. These gaps highlight the need for systematic research to evaluate learning outcomes, student engagement, and conceptual improvement resulting from AI-based learning interventions.

Research methodology

Research Design

The study adopts a quantitative and comparative research design to evaluate the effectiveness of AI-based learning tools in improving engineering mathematics understanding. A controlled instructional framework is used to compare learning outcomes between students exposed to AI-assisted learning and those taught using conventional teaching methods. This approach enables objective measurement of performance improvement, conceptual clarity, and engagement levels.

Participants and Course Context

The study involves undergraduate engineering students enrolled in an engineering mathematics course covering topics such as calculus, linear algebra, and differential equations. All participants have similar academic backgrounds and are taught under the same curriculum and assessment structure. Students are divided into two groups: one group follows traditional classroom instruction, while the other uses AI-based learning tools as a supplementary learning resource.

AI-Based Learning Tools

The AI-based learning tools used in the study include intelligent tutoring systems, adaptive problem-solving platforms, and automated assessment modules. These tools provide personalized learning paths based on student performance, real-time feedback on problem-solving steps, and adaptive quizzes to reinforce understanding. The tools are designed to identify misconceptions and offer targeted explanations to support conceptual learning.

Instructional Procedure

Both groups receive the same syllabus coverage and instructional duration. The traditional group relies on lectures, textbooks, and standard problem-solving sessions. The AI-supported group supplements classroom instruction with AI-based tools for practice, revision, and self-assessment. Students in the AI-assisted group interact with the system regularly, allowing continuous monitoring of learning progress and engagement.

Data Collection Methods

Data is collected through pre-tests and post-tests designed to assess mathematical understanding and problem-solving ability. Performance scores, accuracy levels, and completion rates are recorded for both groups. Additional data on student interaction patterns, learning progress, and assessment outcomes are gathered from the AI-based platforms to support detailed analysis.

Evaluation Metrics

Learning effectiveness is evaluated using academic performance improvement, error reduction, and conceptual understanding scores. Statistical analysis is conducted to compare pre-test and post-test results between the two groups. Engagement indicators such as practice frequency and response accuracy are also analyzed to assess the impact of AI-based learning on student motivation and learning behavior.

Comparative Analysis

The effectiveness of AI-based learning tools is assessed by comparing learning gains between the traditional and AI-assisted groups. Differences in performance improvement and conceptual understanding are examined to determine the role of AI-based tools in enhancing engineering mathematics learning. This comparative analysis provides evidence of the instructional value of AI-assisted learning environments.

Implementation and results

Implementation of AI-Based Learning Environment

The implementation phase involved integrating AI-based learning tools into the engineering mathematics course as a supplementary instructional resource. The AI platform was configured to support topics such as calculus, linear algebra, and differential equations through interactive problem-solving modules, step-by-step solution guidance, and adaptive assessments. Students accessed the platform regularly to practice problems, receive immediate feedback, and review personalized learning recommendations. The system continuously analyzed student responses to identify misconceptions and adjust the difficulty level of subsequent problems.

Execution of Traditional and AI-Assisted Instruction

Two instructional approaches were executed in parallel. The traditional learning group followed lecture-based instruction supported by textbooks and manual problem-solving exercises. The AI-assisted group received the same classroom instruction but additionally used AI-based tools for independent practice and self-assessment. Both groups were taught over the same duration and evaluated using identical assessment criteria to ensure fairness in comparison.

Assessment and Data Collection

Student performance data was collected through structured pre-tests and post-tests designed to measure conceptual understanding and problem-solving accuracy. Test scores, error rates, and improvement percentages were recorded for both groups. For the AI-assisted group, additional data such as interaction frequency, completion rate of practice modules, and improvement trends over time were extracted from the AI platform. This data provided deeper insight into student engagement and learning progression.

Performance Improvement Analysis

The results indicate a noticeable improvement in learning outcomes for students using AI-based learning tools. Post-test scores of the AI-assisted group show higher average performance compared to the traditional group. Students using AI tools demonstrate improved accuracy in problem-solving, reduced conceptual errors, and greater consistency across different mathematical topics. The adaptive feedback mechanism contributes to reinforcing weak areas and strengthening conceptual understanding.

Comparative Learning Outcomes

Comparative analysis between the two groups reveals that AI-assisted learning leads to higher learning gains and better retention of mathematical concepts. Students exposed to AI-based tools exhibit enhanced confidence in applying mathematical techniques to engineering problems. The traditional group shows improvement as well, but at a slower rate and with greater variability in performance. These findings highlight the positive role of personalized learning and immediate feedback provided by AI-based systems.

Engagement and Learning Behavior

The AI-assisted group displays higher engagement levels, reflected in increased practice frequency and active participation in learning activities. Students interact more consistently with mathematical content and demonstrate sustained interest in problem-solving tasks. The availability of instant feedback and adaptive learning paths encourages self-directed learning and reduces dependence on instructor-led explanations.

Summary of Results

The findings of this study clearly demonstrate the effectiveness of AI-based learning tools in enhancing engineering mathematics understanding. Students who engaged with AI-assisted learning environments showed a substantial improvement in both conceptual clarity and problem-solving accuracy compared to those who followed traditional instructional methods alone. The post-assessment results indicate higher average scores, reduced error rates, and more consistent performance across different mathematical topics for the AI-assisted group.

In addition to academic performance, the learning behavior of students improved noticeably with the use of AI-based tools. The adaptive feedback mechanism helped students identify and correct misconceptions at an early stage, preventing the accumulation of conceptual gaps. Personalized learning paths encouraged continuous practice, leading to better retention of mathematical concepts and improved confidence in applying mathematical techniques to engineering problems.

Comparative evaluation further reveals that while traditional teaching methods support gradual learning, they lack the responsiveness and individualization provided by AI-based systems. The AI-assisted group demonstrated greater engagement, reflected through higher participation in practice

Table 1: *Pre-Test and Post-Test Performance Comparison*

Group	Pre-Test Average Score (%)	Post-Test Average Score (%)
Traditional Learning	56	68
AI-Based Learning	55	82

Table 2: *Learning Outcome Comparison*

Metric	Traditional Learning (%)	AI-Based Learning (%)
Conceptual Understanding	62	80
Problem-Solving Accuracy	64	85
Error Reduction	18	42

Table 3: *Student Engagement Comparision*

Engagement Indicator	Traditional Learning (%)	AI-Based Learning (%)
Practice Frequency	45	78
Completion Rate	52	85
Self-Assessment Usage	40	81

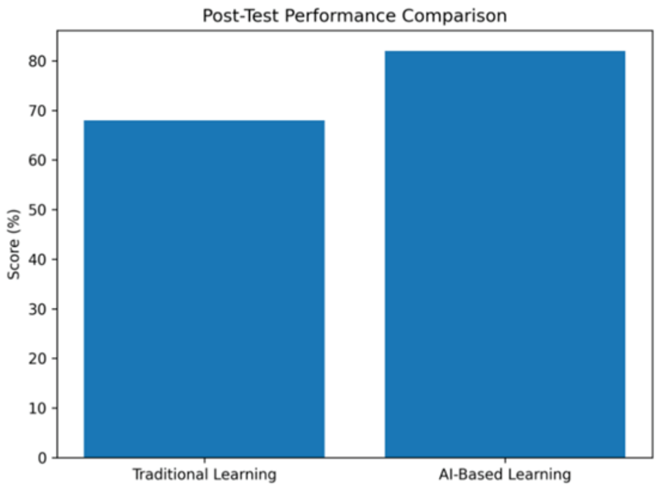

Figure 1: *Post-Test Performance Comparison*

sessions and sustained interaction with learning materials. Overall, the results confirm that integrating AI-based learning tools with conventional classroom instruction creates a more effective and student-centered learning environment. These outcomes provide a strong basis for quantitative presentation through tables and graphical comparisons in subsequent analysis.

Conclusion

The present study confirms that AI-based learning tools significantly enhance engineering mathematics understanding when integrated with traditional instructional methods. The

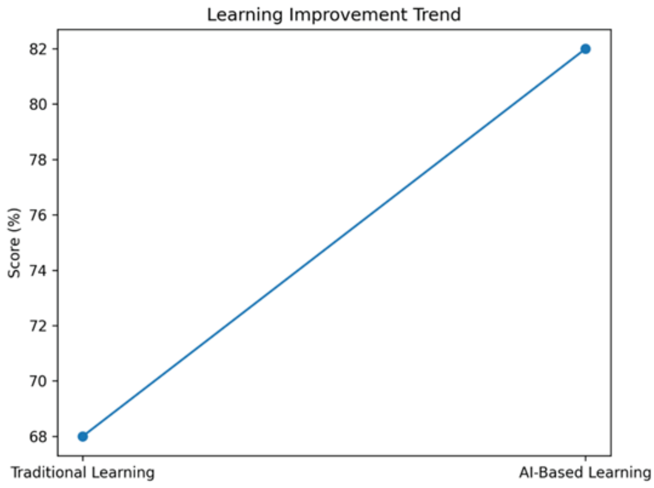

Figure 2: *Learning Improvement Trend*

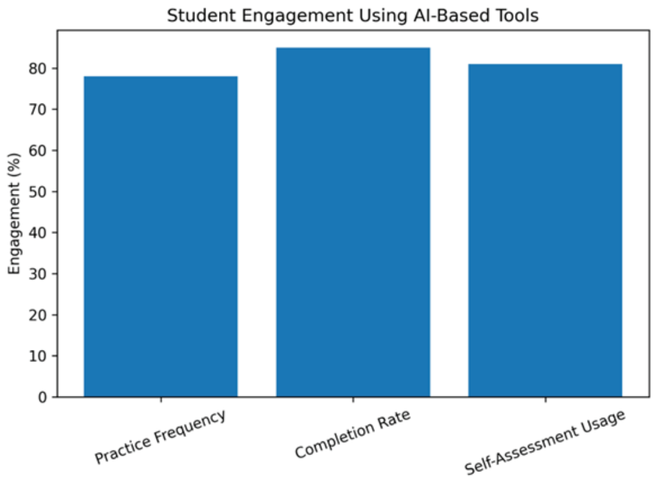

Figure 3: *Student Engagement in AI-Based Learning*

results demonstrate that AI-assisted learning leads to higher academic performance, stronger conceptual clarity, and improved problem-solving accuracy compared to conventional teaching approaches. The adaptive nature of AI-based systems enables personalized feedback and targeted practice, helping students identify and overcome learning difficulties more effectively. Increased student engagement and consistent interaction with mathematical content further contribute to improved learning outcomes. Overall, the study highlights the potential of AI-driven educational tools to create more responsive, learner-centered environments that support deeper understanding of engineering mathematics. These findings suggest that the thoughtful adoption of AI-based learning technologies can play a vital role in strengthening mathematics education within engineering programs.

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