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Leveraging active learning practices for effectiveness of higher education: performance based investigation

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ABSTRACT

Engineering graduates in India struggle with employability due to outdated curricula and ineffective teaching methods, which limit their ability to apply knowledge and think critically. A performance-based study investigated the impact of active learning (AL) techniques in technical education using methods like concept mapping, role-playing, virtual labs, and collaborative coding in computer science and engineering courses. The findings showed a 35% to 40% improvement in academic results compared to traditional methods, along with significant boosts in student engagement, comprehension, and critical thinking. Student feedback and performance evaluations strongly favored AL. Cluster analysis revealed fewer slow learners, highlighting its effectiveness in meeting diverse needs. The study concludes that integrating AL can better prepare students for the job market and enrich their educational experience.

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1. INTRODUCTION

In recent years, there has been a growing focus on improving educational techniques in engineering and computer science to better equip students for the evolving job market. Technical education in India plays a pivotal role in driving socio-economic development, yet the employability of engineering graduates remains a significant concern. Many graduates struggle to apply theoretical knowledge to real-world problems that demand critical thinking and problem-solving skills [1]. The traditional teaching methods often fail to bridge the gap between theoretical knowledge and its practical application and results in lack of critical skills required in professional environments. To address these issues, there has been a shift toward innovative teaching approaches that enhance student engagement, improve knowledge retention, and bridge the gap between theory and practice [2], [3]. Active learning (AL) has emerged as a promising teaching strategy that involves students in interactive activities like problem-solving, group discussions, projects, and collaborative learning, making it a promising solution for transforming the educational landscape in engineering education.

Despite its potential, traditional education methods continue to dominate, with many institutions slow to adopt more dynamic teaching practices [4]. This has contributed to a widening gap between academic preparation and the demands of the workforce. Graduates often lack the critical thinking, collaboration, and adaptability required in the modern job market. Furthermore, improper implementation of AL can lead to other challenges, such as insufficient interaction between students and instructors, an overemphasis on theory, and a lack of practical, hands-on experience. Such issues may limit students' real-world problem-solving skills, communication abilities, and overall readiness for employment. In India, where engineering graduates are expected to contribute to both technological innovation and economic growth, the inability to apply learned knowledge to real-world scenarios is a pressing issue. Therefore, there is a need to identify the factors that impact blended learning to improve students' performances and enhance blended learning [5]. This study proposes the integration of active learning techniques (ALTs) into technical education to enhance the employability of engineering graduates.

By incorporating methods such as concept mapping, role-playing, virtual labs, self-directed learning, and collaborative projects as depicted in Figure 1, AL helps students engage more deeply with course material and develop critical skills like teamwork, problem-solving, and communication [6]. Through practical, performance-based evaluations, the study demonstrates how these techniques improve learning outcomes and better prepare students for the demands of the modern job market. These approaches personalize education to individual student preferences, making it more engaging and practical. By encouraging active student participation and providing opportunities for hands-on application of theoretical concepts, the proposed solution aims to bridge the gap between classroom learning and real-world engineering challenges [7]. Through structured, performance-based evaluations, the research demonstrates that these techniques not only improve academic performance but also prepare students for the demands of the contemporary job market, addressing the gaps left by traditional teaching methods.

Figure 1. Various pedagogical techniques for AL process

2. METHOD AND RELATED WORK

In recent years, there has been a growing body of research evaluating and comparing the use of AL as a teaching strategy in computer science, as evidenced in previous studies [8]–[10]. These studies aim to showcase the utility of AL and its application as an effective teaching method. They underscore AL as a potential tool for enhancing computer science education, ultimately reducing the attrition rates in this field. Liao and Ringler [11] have conducted an experiment comparing the learning experiences of students in traditional face-to-face lectures with those in virtual settings. Their findings indicate that while the hybrid virtual classroom offers flexibility by allowing students to choose when and where to attend the course, it also poses challenges for both educators and remote learners. Ariza [12] argue that many tools and environments designed for teaching programming in computer science have not yielded the expected results in terms of enhancing students' learning experiences. Their research highlights some significant studies that have explored active programming learning approaches for high school and university students, contributing to the creation of innovative educational scenarios centered around active programming learning. Bezerra *et al.* [13] have published an experiential report on how robotics can serve as an effective tool within the context of AL in education. They suggest that robotics in education holds promise as a strategy for implementing AL, promoting greater student participation and interest, both in and out of the classroom.

Videnovik *et al.* [14] proposed a discussion on evaluating how principles, values, techniques, and agile development processes can be integrated with AL to optimize the teaching and learning processes, particularly in introductory programming courses for high school students. The goal is to explore how these active techniques, widely discussed in the literature, can be harmonized with agile software engineering practices. Greer *et al.* [15] provided a systematic literature review on the use of digital games in teaching programming to beginners in computing at the university level in Brazil over the last decade. The authors argue that teaching programming is an integral part of the foundational academic training in computer science and related fields. In summary, these previous studies collectively demonstrate that while AL holds the potential to significantly enhance computer science education, its adoption still faces challenges. These challenges primarily revolve around the resistance of some educators to embrace new teaching techniques and the need for students to actively engage in their learning, both inside and outside the classroom. These factors can negatively impact the development of computational thinking and learning computing [16], [17].

The study addressed the employability concerns of engineering graduates in technical education by exploring innovative teaching methods, particularly ALTs. It aimed to enhance students' learning experiences, foster critical thinking, and bridge the gap between theoretical knowledge and practical application. The study addresses key challenges in technical education, such as limited knowledge application, outdated curricula, and ineffective teaching methods, by implementing AL practices like concept mapping, role-playing, virtual labs, self-directed study, and flipped classrooms. These methods were assessed for their effectiveness in enhancing learning outcomes in computer science and engineering. The study revealed positive outcomes, including increased student engagement, improved comprehension, enhanced critical thinking, and better application of theoretical knowledge. Performance evaluations and student feedback showed a preference for AL over traditional methods, highlighting its effectiveness in fostering collaboration and problem-solving skills. The study concludes that integrating AL can significantly improve learning outcomes, better prepare students for the modern job market, and provide a more enriching educational experience.

3. PROPOSED METHOD AND OUTCOME

In the AL method known as "concept mapping", a specific in-class activity was conducted. The instructor began with a 30-minute explanation of relevant concepts, highlighting the central topic and the subtopics to be included in the students' concept maps. After discussing and addressing student queries, students were instructed to create individual concept maps on the topic. Table 1 lists various ALTs used to enhance student learning experiences [18]–[24]. Over the past semester, extensive research has been dedicated to implementing these techniques, aiming to improve learning outcomes, reduce cognitive load, increase student engagement, promote technological acceptance, and enhance system usability. The findings indicate that these interactive and immersive technologies have positively impacted engineering education and hold significant potential for broader application in other educational fields.

Students were encouraged to brainstorm, identify, and organize key concepts from the lesson, creating outlines before constructing their concept maps. Each student then developed a concept map based on their understanding, as shown in Figure 2. The instructor evaluated these maps to assess comprehension and adjusted the lesson accordingly. In another activity, students were presented with images related to technical terms using PowerPoint slides. They were tasked with recognizing these images, identifying the terms, and then sharing definitions and related content with the class. Additionally, a role-play activity was conducted in-class, illustrated in Figure 3. Students were assigned specific roles related to a problem scenario. Before the role-play, there was an open discussion to stimulate critical thinking and clarify the problem. Students were encouraged to use their imagination to fully immerse themselves in their roles. These ALTs—concept mapping, image recognition, and role-playing—were designed to enhance student engagement, comprehension, and critical thinking [25], [26]. By integrating these interactive methods, the study demonstrated effective strategies for improving the learning experience in engineering education, fostering a deeper understanding and encouraging practical application of knowledge.

The study explored the use of virtual labs and various ALTs to enhance student engagement, comprehension, and problem-solving skills in engineering education. Virtual labs [27], [28] provided an immersive and flexible learning experience, allowing students to conduct experiments, analyze data, and explore scientific concepts in a virtual environment. These labs offered on-demand access, enabling students to reinforce their understanding of complex principles at their own pace, from any location with an internet connection. By promoting self-guided learning, virtual labs helped students engage deeply with subjects like computer networks, enhancing their grasp of theoretical knowledge and preparing them for the demands of the modern job market. The study also incorporated several innovative pedagogical practices, such as "think-pair-share," team-based activities, and group exercises, to further enrich the learning experience. After explaining SQL injection attacks, the "think-pair-share" technique was implemented. Students first reflected individually on real-world examples of SQL injection attacks and conducted web searches to identify different types and methods. They then paired up to share insights, with selected pairs presenting their findings to the class, fostering peer learning and critical discussion.

Table 1. Summary of various AL approaches implemented and their key outcomes

Course topic	ALT approach	Key findings and reflective critique	Outcome	Evaluation techniques
Transmission media	Concept map [18]	Students present and discuss their maps with peers, clarifying misconceptions and promoting deeper understanding by integrating concepts for better grasp.	82% of students attended the Internal Assessment question and secured good marks.	Rubric based activity assessment
Hidden and exposed node problem	Role play [19]	Students comprehend exposed terminal concepts and identify hidden terminal issues in wireless media. Some may not participate or lack skills for role-playing.	In the end-semester exam, students successfully answered questions at the apply/analyze knowledge level, yielding good grades.	Students attitude and perception
Measuring network performance	Virtual lab [20]	Helps students develop a comprehensive understanding of network concepts and gain hands-on experience in managing and troubleshooting networks virtually.	Empowers students to apply theoretical knowledge practically, enhancing networking skills and readiness for real-world challenges.	Knowledge development, learning and performance measurement.
Enhanced ER model	JIGSAW learning [21]	Students work as a team, explaining concepts through knowledge sharing, fostering understanding in a group discussion format.	Improves communication and teamwork skills, preparing students for future workplace group discussions.	Efficiency in teamwork and comprehensibility was evaluated.
Deadlock handling	Flipped classroom [22]	Students appreciate the flexibility to study at their own pace, fostering collaboration and one-to-one interactions.	Enhances self-exploration opportunities for students, leading to a deeper understanding of the subject.	Learning and quality of teaching was analyzed
Query processing overview algorithms for selection, sorting and join operations	Collaborative coding [23]	This activity aids students in understanding algorithmic steps and pseudo code, promoting a comprehensive understanding of query costs.	Improves students' programming and coding skills, with a noticeable increase in performance from 58% to 75%.	Laboratory skill assessment, psychomotor skills
SQL injection	Think-pair-share [24]	Working in pairs facilitates knowledge sharing and deeper understanding, fostering an interactive and friendly classroom atmosphere.	Discusses various reasoning and justification-based questions, enabling students to solve real-time application/case study problems effectively.	Rubric based activity assessments.

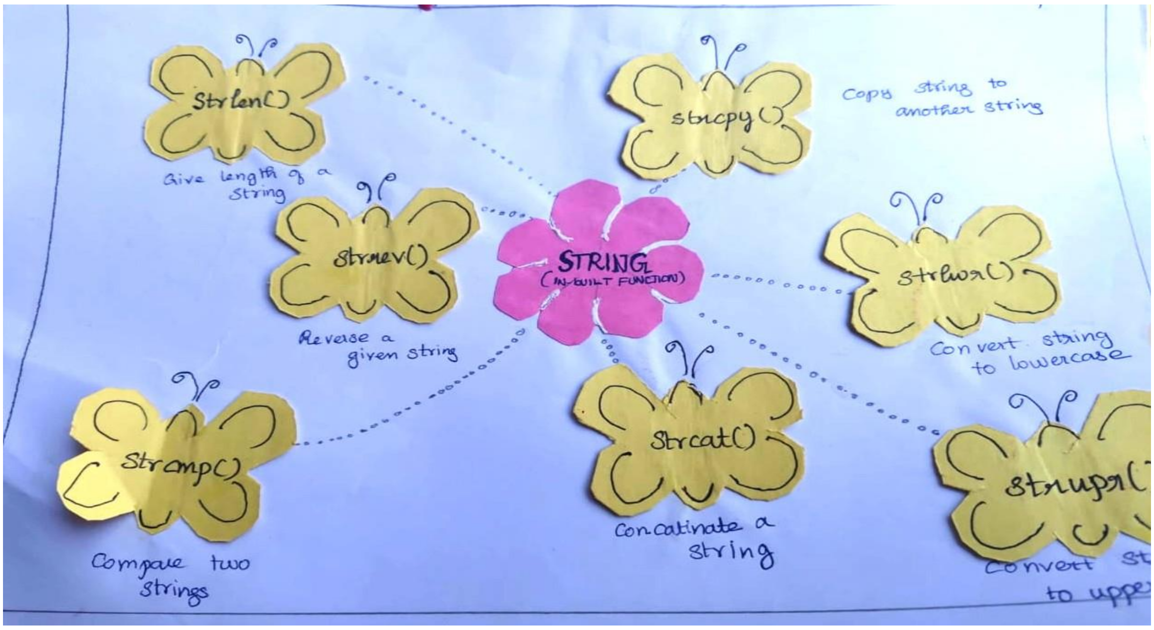

Figure 2. Concept map for the topic “transmission media” designed by the students

Figure 3. Implementation of role play activity, “JIGSAW” learning activity, think pair share activity

Another team-based activity focused on algorithms. Students were given worksheets with partially completed algorithmic code and pseudo-code, which they needed to finish. The instructor provided guidance during the class, addressing doubts and correcting errors to ensure understanding. At the session’s end, the correct solutions and execution processes were reviewed, allowing students to solidify their knowledge and improve their problem-solving skills. For teaching entity-relationship (ER) models and diagrams, the study introduced a group activity. Students were divided into groups, with each member assigned a specific application in various domains. After constructing ER diagrams, one student from each group joined an “expert group” to model the diagram for their application. These experts then returned to their original groups to share their knowledge, fostering a collaborative learning environment and ensuring all students gained comprehensive insights into the topic. These AL methods—virtual labs, “think-pair-share” for SQL injection, algorithm-focused team activities, and ER diagram group exercises—proved effective in promoting engagement, collaboration, and a deeper understanding of complex subjects. By integrating these strategies, the study demonstrated how ALTs could significantly enhance the learning experience in engineering education, equipping students with the skills necessary to excel in both academic and professional settings.

In summary, the study highlighted the effectiveness of virtual labs and ALTs in transforming student engagement and academic performance. These methods fostered a practical, interactive approach to learning, bridging the gap between theoretical knowledge and real-world application. Through self-guided exploration, collaborative activities, and hands-on exercises, students were able to deepen their understanding of key concepts, improve problem-solving abilities, and prepare more effectively for the challenges of the contemporary job market. The study underscores the importance of incorporating AL strategies into engineering education to create a more dynamic and enriching learning environment.

4. RESULTS AND DISCUSSION

Performance evaluation of ALTs is crucial for several reasons. First and foremost, it provides educators with valuable insights into the effectiveness of their teaching methods. By assessing how students respond to AL strategies, educators can adapt and refine their approaches to better cater to students' needs and optimize learning outcomes. Secondly, performance evaluation allows students to reflect on their own learning experiences. It encourages self-assessment, helping students recognize their strengths and areas requiring improvement.

Self-awareness can motivate students to take ownership of their learning and become more active participants in the educational process. The various methods of performance evaluation for ALTs are discussed here. One primary method is by assessing learning outcomes. Educators can compare the performance of students who have experienced AL with those who have not, using metrics such as test scores, project outcomes, or the quality of class discussions. This comparison helps determine if AL enhances comprehension and retention of the material. This research is based on a dataset of assessment scores from 180 undergraduate students enrolled in computer domain courses. The internal assessment scores include results from IAT1 and IAT2 of five courses (internal assessment tests 1 and 2), conducted using two distinct teaching methodologies: the traditional approach and the AL method. Initially, the class average marks of IAT1 and IAT2 from the traditional classroom approach are compared with those from the AL classroom approach, as shown in Figure 4. The IAT1 scores derive from the traditional teaching approach, while the IAT2 scores come from various innovative AL methodologies, also shown in Figure 4. The comparison results indicate that the average student marks increased by a percentage when AL approaches were implemented compared to the traditional classroom approach.

Clusters are formed based on the assessment marks of IAT1 and IAT2 in both the traditional and AL classroom approaches, enabling the course instructor to discern students' proficiency levels. Three clusters are established: group A (experts), group B (average), and group C (slower Learners), color-coded in green, blue, and red, respectively. Clusters are employed to compare the performances of IATs in the traditional approach with those in the AL approach, as illustrated in Figure 5. The results show a scarcity of slow learners categorized in group C (red) in the AL practice, whereas there is a surplus of slow learners in group C (red) in the traditional classroom practice. Overall, the study demonstrates that ALTs significantly enhance student performance and reduce the number of slower learners, highlighting the effectiveness of these methods in improving educational outcomes. Gathering feedback directly from students is invaluable. Surveys, questionnaires, and open discussions can provide insights into students' perceptions of AL methods. They can express their preferences, challenges faced, and suggestions for improvement, offering a student-centric perspective. Figure 6 reveals a total of 174 opinions, with 41 expressing positive emotions, 18 conveying negative sentiments, and 115 offering neutral opinions about the traditional approach. For the AL classroom approach, 178 opinions are collected, with 108 reflecting positive emotions, 4 indicating negative sentiments, and 66 maintaining a neutral stance.

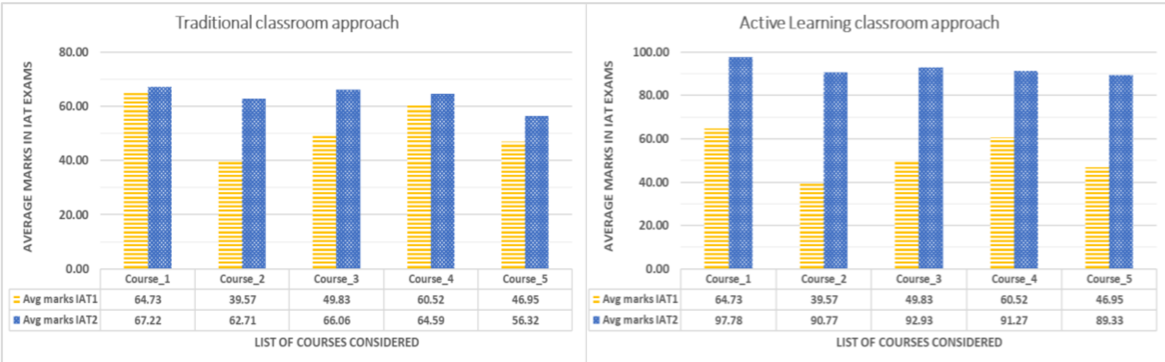

Figure 4. Comparisons of the IAT1 and IAT2 marks obtained from traditional classroom approach

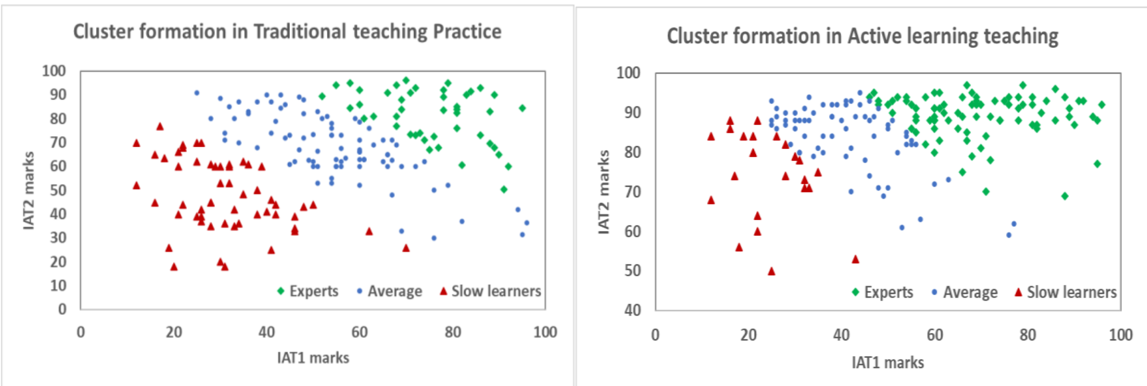

Figure 5. Cluster analysis of the student's groups namely A, B, C and their performances in IATs

Educators can observe students' performances during AL activities, noting their engagement, collaboration, and critical thinking. This research aims to identify slow learners and evaluate the impact of AL models on their performance. Figure 5 shows the number of slow learners (represented as red dots) who scored below passing marks in IAT1 and IAT2 assessment tests. In the traditional classroom approach, 14.44% of students (27 out of 180) were identified as slow learners, consistently scoring below the passing threshold in both assessments. Remarkably, this percentage dropped to 2.2% (4 students) with the implementation of AL methodologies. This significant decrease emphasizes the positive impact of novel ALTs, facilitated by advancements in ICT tools and models, on student motivation and performance. The findings highlight several key implications for the future of technical education. Implementing ALTs leads to better comprehension, retention, and application of knowledge, ultimately improving students' academic performance and readiness for the job market. AL encourages critical thinking, creative problem-solving, and effective collaboration, essential skills in the rapidly evolving fields of technology and engineering. These approaches cater to diverse learning styles and preferences, promoting inclusivity in the classroom and accommodating the needs of a wide range of students. By emphasizing practical application and real-world problem-solving, AL helps students develop skills and competencies demanded by employers, increasing their employability and competitiveness. Educators can benefit from training and support in implementing AL strategies effectively, fostering a more dynamic and engaging teaching environment and continuous improvement in teaching practices. Continued research into the effectiveness of AL methods and the development of new technologies and pedagogical approaches can further enhance the quality of technical education. This ongoing innovation will drive improvements in educational practices, ensuring that students are well-prepared for the demands of the contemporary job market and capable of contributing effectively to their chosen fields.

The study explores how ALTs enhance employability among engineering graduates by fostering critical skills highly valued in today's job market [29], [30]. Methods such as concept mapping, role-playing, and virtual labs were shown to improve academic performance while cultivating problem-solving, critical thinking, collaboration, and adaptability. Role-playing simulated real-world engineering scenarios, allowing students to apply theoretical knowledge to practical problems, thus reflecting workplace challenges and helping students develop quick thinking, communication, and teamwork skills. Virtual labs, on the other hand, promoted self-directed learning, enabling students to experiment with complex concepts and develop a deeper understanding, reflecting the adaptability needed in many engineering roles. The study found that students engaged in active AL learning techniques exhibited significant improvement in both academic metrics and essential soft skills like leadership and teamwork. This connection to employability was reinforced by student success in securing roles such as technical support engineer, graduate engineer trainee, and programmer analyst trainee. Student feedback also indicated increased confidence and job readiness, aligning with research that suggests AL bridges the gap between academic preparation and professional demands. In conclusion, the research shows that integrating ALTs in technical education equips students with both the hard and soft skills needed for modern engineering roles, significantly boosting their employability.

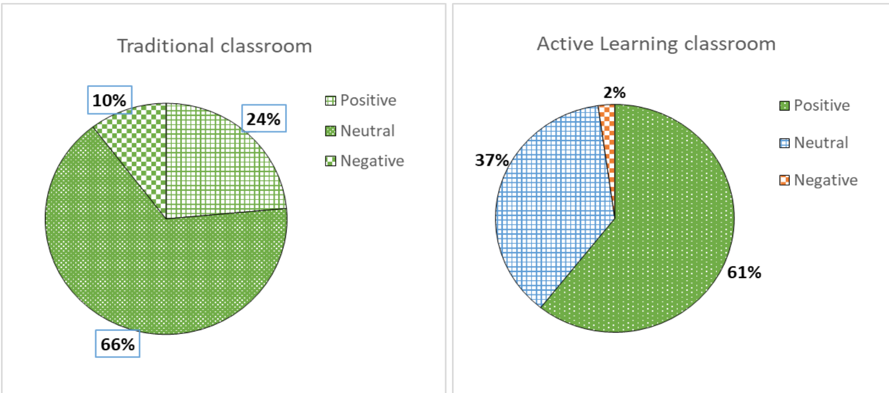

Figure 6. Comparison of student's feedbacks and opinion - traditional vs. AL approach

5. CONCLUSION

Through a performance-based investigation, the study aimed to explore the effectiveness of ALTs in enhancing student engagement, comprehension, and critical thinking skills. By implementing various AL practices across different topics, the study sought to bridge the gap between theoretical knowledge and practical application, ultimately preparing students for the dynamic demands of the modern job market. Furthermore, this research compares educational technology strategies such as roleplay, JIGSAW, collaborative learning and flipped classrooms with traditional classrooms. The findings of this study on integration of innovative teaching methods such as concept mapping, role-playing, virtual labs, collaborative coding, and flipped classrooms, students demonstrated increased levels of engagement, participation, and knowledge retention. Performance evaluations revealed improved learning outcomes, with students exhibiting higher levels of comprehension and problem-solving abilities compared to traditional teaching methods. The clustering analysis provides valuable insights into learner's behavior towards the chosen teaching methodology, revealing that innovative learning approaches enhance student's performance compared to traditional classroom methods.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known conflict of interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY

The data that support the findings of this study are available on request from the corresponding author [VSK]. The data, which contain information that could compromise the privacy of research participants, are not publicly available due to certain restrictions.

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