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ORIGINAL

Effectiveness of the PBLMAR Model in Improving Student Learning Outcomes: An N-Gain Analysis in Air Conditioning Technology Course

Eficacia del modelo PBLMAR para mejorar los resultados de aprendizaje de los estudiantes: un análisis N-Gain en el curso de tecnología de aire acondicionado

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ABSTRACT

Introduction: this study aims to evaluate the effectiveness of the Problem-Based Learning model assisted by Mobile Augmented Reality (PBLMAR) in improving student learning outcomes in the Air Conditioning Technology course. The integration of MAR technology is expected to support student-centered learning and enhance conceptual understanding in vocational education settings.
Method: a quasi-experimental method was applied using a one-group pretest-posttest design. Data collection involved pretest and posttest assessments administered to 30 vocational students. The normalized gain (N-Gain) was calculated using Microsoft Excel to measure the increase in students' cognitive achievement after implementing the PBLMAR model. N-Gain results were interpreted using standard criteria (high, medium, low).
Results: the analysis showed that the average N-Gain score was 0,7; which falls into the category, high category. This indicates a significant improvement in student learning outcomes. Additionally, student responses suggested positive engagement and interest in using MAR-based learning media.
Conclusions: the PBLMAR model is effective in improving students' conceptual understanding and engagement in the Air Conditioning Technology course. The use of N-Gain analysis provides clear evidence of the model's impact, supporting its further application in vocational education.

Keywords: PBLMAR; N-Gain; Effectiveness; Learning Outcomes; Mobile Augmented Reality; Vocational Education.

RESUMEN

Introducción: este estudio busca evaluar la eficacia del modelo de Aprendizaje Basado en Problemas asistido por Realidad Aumentada Móvil (PBLMAR) para mejorar los resultados de aprendizaje de los estudiantes en el curso de Tecnología de Aire Acondicionado. Se espera que la integración de la tecnología MAR fomente el aprendizaje centrado en el estudiante y mejore la comprensión conceptual en entornos de formación profesional.
Método: se aplicó un método cuasiexperimental con un diseño pretest-postest de un solo grupo. La recopilación de datos incluyó evaluaciones pretest y postest administradas a 30 studiantes de formación profesional. La ganancia normalizada (Ganancia-N) se calculó con Microsoft Excel para medir el aumento en el rendimiento

cognitivo de los estudiantes tras la implementación del modelo PBLMAR. Los resultados de la Ganancia-N se interpretaron utilizando criterios estándar (alto, medio, bajo).
Resultados: el análisis mostró que la puntuación media de la Ganancia-N fue de 0,7; lo que se sitúa en la categoría alta. Esto indica una mejora significativa en los resultados de aprendizaje de los estudiantes. Además, las respuestas de los estudiantes sugirieron una participación positiva e interés en el uso de medios de aprendizaje basados en MAR.
Conclusiones: el modelo PBLMAR es eficaz para mejorar la comprensión conceptual y la participación de los estudiantes en el curso de Tecnología de Aire Acondicionado. El uso del análisis N-Gain proporciona evidencia clara del impacto del modelo, lo que respalda su aplicación en la formación profesional.

Palabras clave: PBLMAR; N-Gain; Efectividad; Resultados de Aprendizaje; Realidad Aumentada Móvil; Formación Professional.

INTRODUCTION

Vocational education plays a pivotal role in preparing students with the practical skills and technical competencies required in today's fast-evolving workforce. In the Indonesian context, the revitalization of vocational education has been a national priority to meet the growing demands of industry and technology.[1] However, a persistent challenge remains, how to design learning experiences that not only transmit theoretical knowledge but also foster higher-order thinking, active engagement, and real-world problem-solving skills.[2] One of the key areas where this challenge is most evident is in courses such as Air Conditioning Technology, which are complex, abstract, and technical in nature.[3]

Students in this subject are expected to understand intricate concepts such as thermodynamics, refrigeration cycles, pressure-temperature relationships, and system diagnostics.[4] Unfortunately, traditional instructional methods dominated by lectures and textbook explanations are often insufficient to help students internalize such concepts.[5,6] Many vocational educators still rely on passive learning strategies, which contribute to limited student motivation, surface-level understanding, and suboptimal academic performance.[7] Several studies have reported that student learning outcomes in vocational technical subjects remain below national competency targets, and dropout or disengagement rates are relatively high.[8]

In response to these challenges, educational researchers and practitioners have called for more innovative, student-centered, and technology-integrated learning models. One such model is Problem-Based Learning (PBL), which positions students as active participants in the learning process by engaging them in authentic, open-ended problems that reflect real world challenges.[9,10] PBL encourages critical thinking, collaboration, and self-directed learning skills highly relevant in vocational fields. Research by[11] supports the effectiveness of PBL in fostering deeper understanding and long-term knowledge retention.

However, while PBL offers a strong pedagogical framework, its implementation in technical subjects often encounters limitations, especially when students are required to visualize abstract systems or mechanisms.[12] This is where technological innovations such as Mobile Augmented Reality (MAR) can significantly enhance the learning experience.[13,14] MAR allows digital information—such as 3D objects, animations, and simulations—to be overlaid onto real environments using smartphones or tablets.[15] This technology enables students to interact with visualized technical content in real-time, making abstract concepts more concrete and engaging. According to,[16] the use of AR in education has shown significant potential in increasing learner motivation, comprehension, and interaction, particularly in science and engineering subjects.

Combining PBL and MAR into an integrated learning model—termed PBLMAR—has the potential to offer the best of worlds, the cognitive depth of problem-solving learning and the visual richness of augmented media.[17] In a PBLMAR setting, students collaboratively work on realistic problems while interacting with AR-based content that visualizes components of air conditioning systems, refrigerant flow, compressor operations, and more. This combination creates a multisensory and contextual learning environment that aligns with the core principles of vocational learning.[18]

Despite its promise, research on the effectiveness of PBLMAR especially in Indonesian vocational education is still very limited.[19] Most prior studies tend to focus either on PBL or AR in isolation, without exploring the pedagogical synergy between them.[20] Furthermore, few studies employ practical and classroom friendly data analysis techniques to evaluate learning effectiveness.[21,22] This presents a research gap that the current study seeks to address.

To evaluate learning effectiveness, this study employs Normalized Gain (N-Gain) analysis a widely used method to measure the degree of improvement in student learning between pretest and posttest.[23,24] N-Gain is particularly useful in educational research because it provides a standardized index of learning gain that can be interpreted across different content areas.[25,26,27,28,29] Additionally, the simplicity of calculating N-Gain using

Microsoft Excel makes it highly accessible for educators conducting classroom-based research.[30,31,32,33,34]

Therefore, this research is designed to assess the effectiveness of the PBLMAR learning model in improving student learning outcomes in the Air Conditioning Technology course through N-Gain analysis. The study not only aims to generate empirical evidence about learning improvement but also seeks to offer insights into the practicality of integrating AR-based media into vocational learning. By doing so, this research contributes to the growing body of literature on digital pedagogies and provides a scalable, data-driven framework for vocational instructors, curriculum designers, and policymakers.

In summary, this study positions itself at the intersection of pedagogical innovation and technological advancement in vocational education. It addresses an urgent educational need enhancing student understanding in complex technical subjects by proposing and empirically evaluating a hybrid learning model that is both engaging and data-supported. The results of this research are expected to have practical implications for improving the quality and effectiveness of vocational teaching, particularly in subjects where abstract concepts and system interactions are core learning challenges.

METHOD

Research Design

This research employs a quasi-experimental design with a one-group pretest-posttest approach to evaluate the effectiveness of the PBLMAR learning model. This design is appropriate for classroom-based studies where full randomization is not feasible but pre- and post-intervention comparisons can reveal learning improvements. The study focuses on assessing cognitive learning outcomes by comparing student scores before and after the implementation of PBLMAR.

Participants

The participants consisted of 30 students enrolled in the Air Conditioning Technology course within an Indonesian vocational automotive education program. The participants were selected using purposive sampling, considering their enrollment in the course and prior exposure to conventional learning methods. All participants followed the same instructional schedule and were introduced to the PBLMAR model as part of their regular coursework.

Learning Model Intervention

The intervention implemented was the Problem-Based Learning with Mobile Augmented Reality (PBLMAR) model. This model integrates problem-solving scenarios related to air conditioning systems with the use of mobile-based augmented reality media. The MAR content was developed specifically for this study and included interactive 3D visualizations of HVAC components (compressor, condenser, evaporator, refrigerant flow, etc.), which students accessed through Android smartphones. During each session, students were divided into small groups, given real-world problem cases, and guided through PBL stages (problem orientation, exploration, analysis, solution, and reflection) while interacting with the AR media.

Instrumentation

To measure learning outcomes, a set of cognitive tests was administered in the form of a pretest and posttest. The tests were developed based on the core competencies of the Air Conditioning Technology course and validated by subject matter experts. The test items consisted of multiple-choice questions and structured short-answer items that measured understanding of system functions, diagnostic procedures, and thermodynamic principles.

Additionally, observation checklists and field notes were used to monitor the learning process and ensure the fidelity of the PBLMAR model implementation.

Data Collection Procedure

a. Pretest: Before the intervention, students were given a pretest to assess their baseline understanding of air conditioning systems.

b. Intervention: Students participated in four learning sessions using the PBLMAR model over a two-week period.

c. Posttest: At the end of the intervention, the same test (with item rearrangement) was administered to measure learning gains.

d. Scoring: Student scores were recorded and analyzed using Microsoft Excel to calculate N-Gain values.

Data Analysis

The effectiveness of the PBLMAR model was evaluated using the Normalized Gain (N-Gain) formula:

$$N - Gain = \frac{Posttest\ Score - Pretest\ Score}{100 - Pretest\ Score}$$

N-Gain values were interpreted using the following criteria:[23]
High : ≥ 0,70
Medium : 0,30 – 0,69
Low : < 0,30
Descriptive statistics such as mean, minimum, and maximum scores were also calculated. Data were tabulated and visualized in Excel to identify patterns of learning improvement across the class.

DEVELOPMENT

The development of the PBLMAR model was guided by the ADDIE instructional design framework, which includes five structured stages: Analysis, Design, Development, Implementation, and Evaluation.[35] This model was selected due to its systematic and iterative nature, allowing for continuous refinement of instructional products. The goal of the development process was to produce a valid, practical, and effective learning model that integrates Problem-Based Learning (PBL) with Mobile Augmented Reality (MAR) to enhance both conceptual and procedural knowledge in the Air Conditioning Technology course within vocational automotive education.

During the analysis stage, syllabus reviews, classroom observations, and interviews with instructors revealed that students struggled to visualize the function and structure of HVAC systems due to abstract content delivery and limited real-world application. Traditional instruction often lacked interactivity and contextual relevance.[36] These findings indicated the need for a learning model that leverages technology to facilitate active learning and visualization of HVAC systems.

In the design phase, a seven-phase PBLMAR learning syntax was formulated based on the principles of constructivism and PBL.[37] These phases include: (1) Problem Orientation through MAR/simulator, (2) Initial Identification and Discussion, (3) Exploration and Investigation with MAR, (4) Data Collection and Analysis, (5) Solution Development and Implementation, (6) Presentation and Discussion of Results, and (7) Evaluation and Reflection. Supporting materials such as student worksheets and media storyboards were designed in alignment with these stages to scaffold inquiry and exploration this can be seen in figure 1.

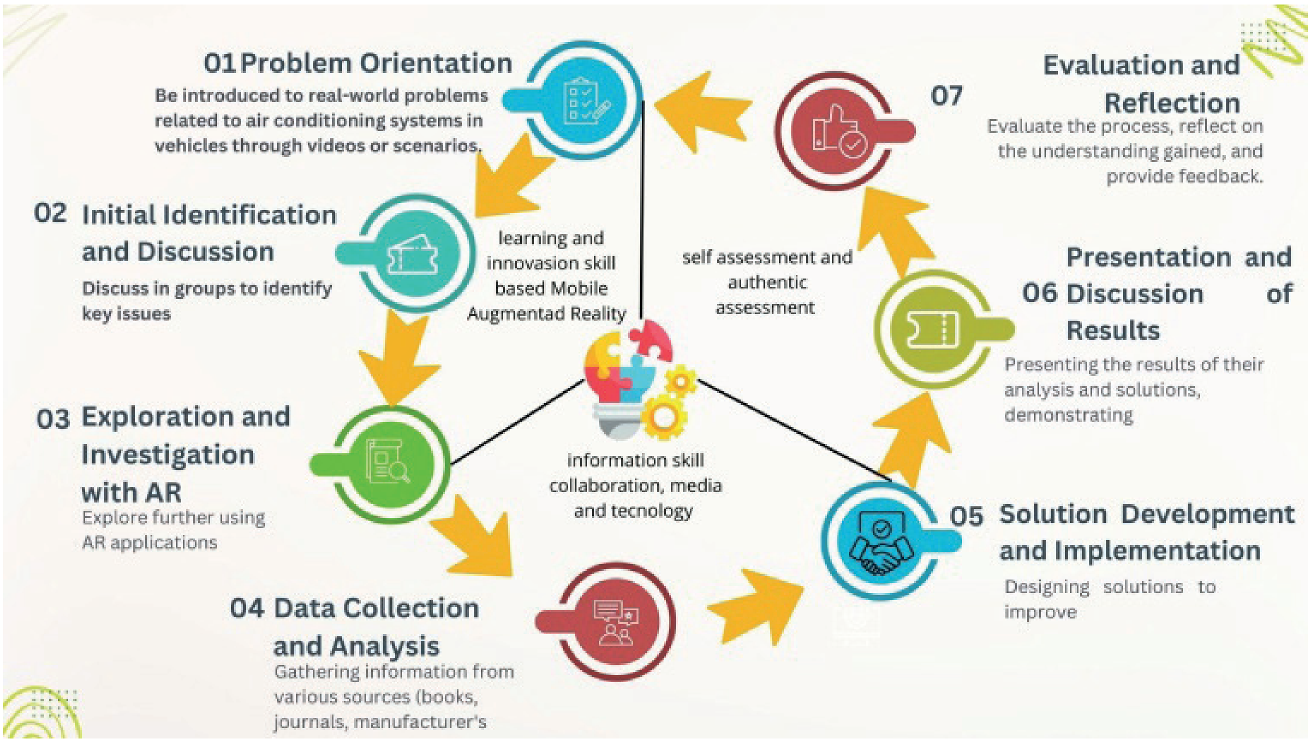

Figure 1. Syntax for Problem Based Learning Model with Augmented Reality (PBLMAR)

The development stage focused on producing the core components of the model. First, a mobile MAR application was developed using Unity and Vuforia SDK, allowing students to interact with 3D visualizations of HVAC components such as compressors, condensers, and evaporators.[38] This application supports learners in comprehending abstract concepts through augmented interactions. Second, Student Worksheets (SWs) were designed to structure problem-based inquiry, integrating tasks that align with the MAR features. Third, a Teacher's Guidebook was created to assist instructors in systematically implementing the PBLMAR model. Additionally, a set of evaluation instruments—including pretest-posttest items, observation rubrics, and expert validation checklists—was constructed to assess validity, practicality, and effectiveness.(39)

The implementation phase involved a limited trial with 30 vocational students. Over four class sessions, students worked in collaborative groups to address HVAC-related problems using the PBLMAR approach. They navigated real-world issues such as refrigerant leakage and compressor malfunction while using the MAR app to visualize system behavior and support their investigations.(40,41)

Lastly, in the evaluation phase, expert validation was conducted by specialists in instructional design, HVAC engineering, and educational media. The feedback obtained focused on improving clarity of visual content, refining problem statements, and simplifying worksheet language. After revisions were made, the model was declared valid and practical. Observations during implementation suggested increased student engagement, better conceptual understanding, and improved problem-solving performance—aligning with prior studies on the efficacy of MAR and PBL in vocational settings.(42,43,44,45,46)

In conclusion, the final product of this development process is a comprehensive PBLMAR learning package that includes an interactive MAR application, inquiry-based learning materials, a teaching guide, and complete evaluation tools. These elements work together to promote an active, visual, and student-centered learning experience tailored to the challenges and demands of vocational education.

RESULTS

The quantitative results of this study demonstrate the significant effectiveness of the Problem-Based Learning model supported by Mobile Augmented Reality (PBLMAR) in enhancing students' cognitive learning outcomes in the Air Conditioning Technology course. The effectiveness of the learning intervention was measured using a pre-experimental design with a one-group pretest-posttest approach. Students' learning gains were calculated using the Normalized Gain (N-Gain) formula, which compares the actual improvement in students' scores to the maximum possible improvement.

From a total of 30 students, the average score before the learning intervention (pre-test) was 38 out of 100, indicating a relatively low level of initial understanding of the course content. Following the implementation of the PBLMAR model, the post-test average significantly increased to 82, reflecting a substantial improvement in students' mastery of HVAC concepts. This increase suggests that students were able to absorb, apply, and contextualize the learning material more effectively after participating in the structured PBLMAR activities. The following is a comparison graph of the Pre-Test and Post-Test values for 30 students who participated in learning with the PBLMAR model, which can be seen in figure 2.

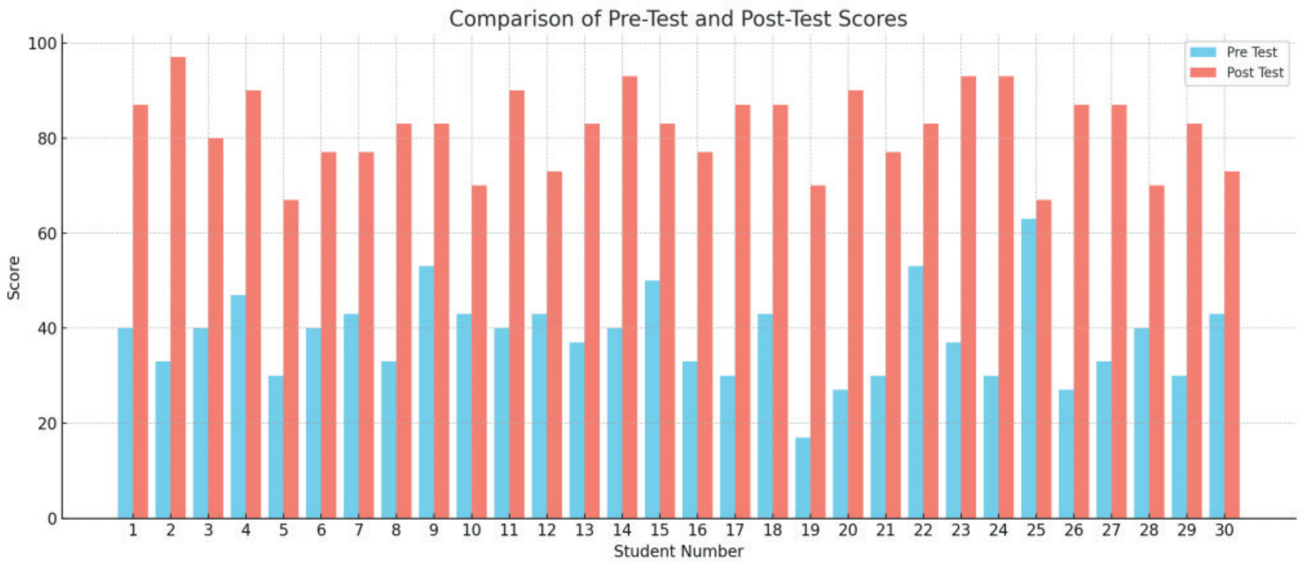

Figure 2. Comparison of Pre-Test and Post-Test scores for 30 students who participated in learning with the PBLMAR model

Next is the N-Gain Score per student graph which shows the increase in the effectiveness of PBLMAR model-based learning in figure 3.

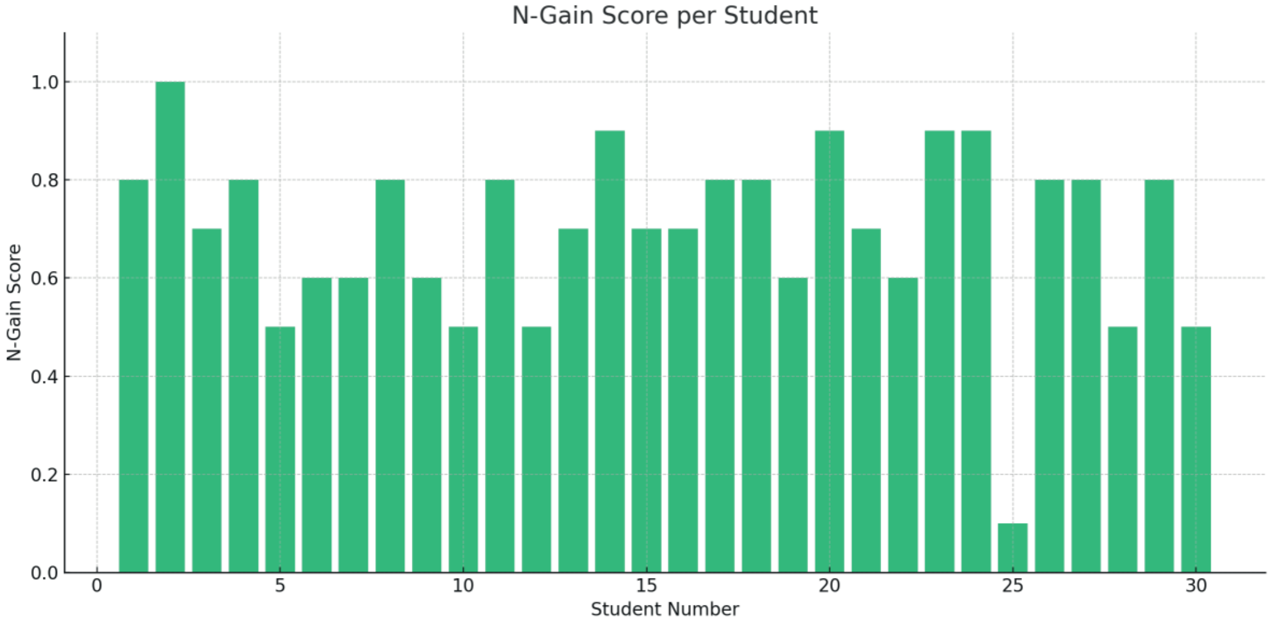

Figure 3. N-Gain Score per Student

From this figure 3, we can see that most participants experienced a significant increase (with an N-Gain score > 0,7), which shows the high effectiveness of this learning model. The N-Gain scores, which reflect the normalized improvement for each student, ranged from 0,1 to 1,0; with a calculated average of 0,7. According to the interpretation criteria proposed by Hake (1999), this value falls into the “high” category of effectiveness, thus indicating that the PBLMAR model had a strong and positive impact on learning outcomes. A closer analysis of the N-Gain distribution shows that: 63,3 % of students (19 out of 30) achieved N-Gain scores in the high category (>0,7), 33,3 % (10 students) were in the medium category (0,3–0,7), only 3,3 % (1 student) fell into the low category (<0,3).

This distribution highlights that the majority of learners not only benefited from the intervention but experienced significant academic improvement.

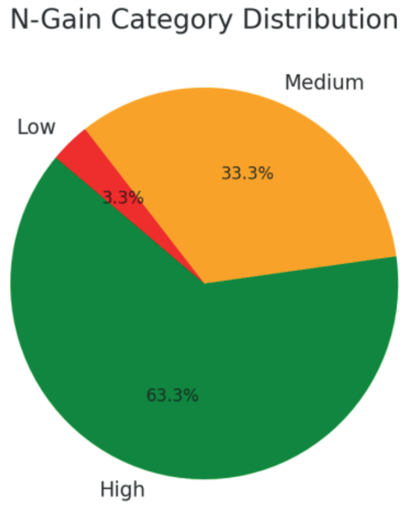

Figure 4. Distribution of Students by N-Gain Category (High, Medium, Low)

To visualize the improvement in student learning more clearly, a boxplot comparison between pre-test and post-test scores is presented in figure 5. The boxplot illustrates a distinct shift in score distribution: the interquartile range (IQR) for the post-test moved higher, and the median score increased substantially. This visual confirms that the improvement was consistent across the sample and not skewed by outliers.

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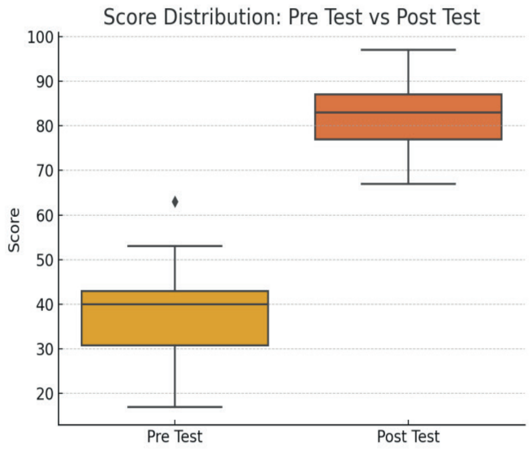

Figure 5. Boxplot of Pre-Test and Post-Test Score Distributions

Additionally, figure 6 presents a line graph showing the individual progression of each student's performance from pre-test to post-test. Nearly all lines in the graph exhibit an upward trajectory, confirming that the majority of students showed individual gains. This visual evidence supports the claim that PBLMAR effectively facilitated knowledge construction, comprehension, and problem-solving capabilities in technical vocational education.

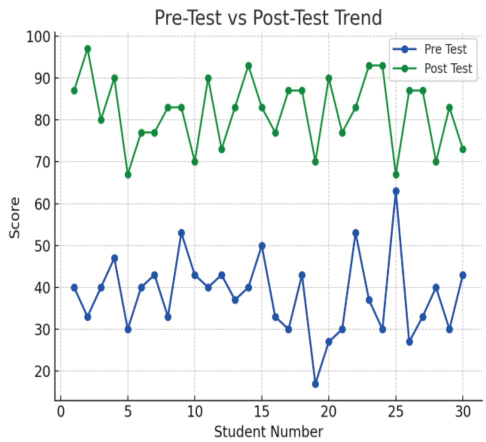

Figure 6. Student-by-Student Score Trend from Pre-Test to Post-Test

These findings are aligned with previous studies on the effectiveness of PBL and MAR, which have emphasized the importance of active engagement, visualization, and contextualized learning environments in improving student understanding and retention of complex material.[25]

The statistical and visual data collected in this study strongly suggest that the PBLMAR model can serve as a powerful pedagogical approach in vocational education, particularly for subjects that require practical comprehension and conceptual clarity such as HVAC systems.

DISCUSSION

The results of this study demonstrate that the PBLMAR learning model—an integration of Problem-Based Learning (PBL) with Mobile Augmented Reality (MAR)—can effectively improve students' cognitive outcomes in the Air Conditioning Technology course. The observed average normalized gain (n-gain) of 0,7 indicates a moderate to high level of learning improvement, which supports the model's potential to enhance conceptual understanding and problem-solving skills in vocational education.

These findings align with previous studies that advocate for the use of augmented reality in technical learning environments. According to,[25] AR facilitates visualization of abstract and complex systems, allowing learners to better understand how components function in a simulated but contextually rich environment. In this study, the MAR simulator enabled students to explore HVAC systems dynamically, encouraging active learning and curiosity.

The structured phases of PBLMAR—especially those involving problem orientation, data investigation, and simulation-based exploration—contributed to a deeper level of engagement and application of knowledge. As indicated by,[11] PBL models support the development of metacognitive and collaborative skills. When enhanced by MAR tools, the learning becomes more immersive, leading to sustained attention and improved retention.

The diversity in n-gain scores among students may reflect varying levels of prior knowledge, digital literacy, and engagement with the MAR tools. While the majority of students achieved moderate to high gains, a small number experienced lower outcomes.[47,48,49,50,51] These anomalies suggest that future implementations should consider scaffolding strategies or personalized support during MAR activities to ensure equitable learning progress.

Moreover, from a practical standpoint, the PBLMAR model proved feasible in vocational classroom settings. Teachers and students reported ease of use, minimal technical disruptions, and a positive overall experience. The learning design, centered around real-world HVAC problems, also improved student motivation by directly connecting theory to practice.

In conclusion, the integration of MAR technology into a problem-based learning framework shows strong potential to transform traditional vocational training into an interactive, student-centered, and outcomes-driven process. Future research may explore longitudinal impacts, integration with industry-standard tools, or adaptations for other engineering-based subjects.

CONCLUSIONS

The findings of this study provide compelling evidence for the effectiveness of the Problem-Based Learning model supported by Mobile Augmented Reality (PBLMAR) in enhancing student learning outcomes in the Air Conditioning Technology course. Through a structured series of seven instructional phases—ranging from problem orientation with MAR to evaluation and reflection—the model successfully guided students through active, inquiry-based, and contextualized learning experiences.

Quantitative results, as measured by pre-test and post-test scores, revealed a significant increase in students' cognitive achievement. The average pre-test score of 38 improved markedly to an average post-test score of 82, yielding an average normalized gain (N-Gain) of 0,7. According to Hake's criteria, this value is categorized as "high," indicating that the PBLMAR model is highly effective. Visualizations, including comparative bar charts, boxplots, and line graphs of individual learning trajectories, reinforced these findings by clearly demonstrating consistent improvement across nearly all students.

The integration of MAR technology played a vital role in creating interactive and immersive learning environments, allowing students to visualize HVAC systems, engage in simulations, and collaborate in solving real-world technical problems. This not only improved understanding but also fostered motivation, critical thinking, and problem-solving skills—competencies essential for vocational education.

Overall, this study concludes that the PBLMAR model is not only valid and practical but also significantly effective in improving cognitive learning outcomes in technical courses. The model holds strong potential for broader implementation in similar vocational and engineering education settings, particularly where complex, system-based understanding is required. Future research is recommended to explore its scalability, long-term retention impact, and integration with other emerging technologies.

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