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THE APPLICATION OF ARTIFICIAL INTELLIGENCE (AI) IN VEHICLE MOTION MECHANICS LEARNING TO OPTIMIZE STUDENTS' CRITICAL THINKING AND PROBLEM-SOLVING SKILLS

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ABSTRACT
The integration of Artificial Intelligence (AI) in vocational education opens up transformative opportunities to develop 21st-century skills, especially critical thinking and problem-solving, which are key competencies for prospective professionals in the automotive sector. This study examines the effectiveness of using AI (Claude and Pollo AI) through the Project-Based Learning (PjBL) model in improving the critical thinking and problem-solving skills of automotive engineering students in the Vehicle Motion Mechanics course. The study, using a pre-experimental intact group comparison design, involved 37 third-semester students, consisting of an experimental group ($n = 18$) and a control group ($n = 19$). The experimental group learned using AI-based PjBL, while the control group received conventional Discovery Learning. Data were collected through validated analytical rubrics and analyzed using an independent samples t-test and effect size. The results showed that the experimental group obtained a much higher critical thinking score (M = 82.45; SD = 6.23) compared to the control group (M = 71.33; SD = 7.89), $t(35) = 4.67; p < 0.001;$ Cohen's $d = 1.52$. Similar improvements were also found in problem-solving skills (M = 84.12; SD = 5.87 vs. M = 69.78; SD = 8.45), $t(35) = 5.89; p < 0.001;$ Cohen's $d = 1.93$, which indicates a strong practical impact. These findings confirm that the integration of AI through PjBL effectively strengthens critical thinking and problem-solving skills in automotive vocational education, while providing empirical evidence to drive technology-based engineering learning transformation.

Keyword: Artificial Intelligence, Critical Thinking, Problem Solving, Vocational Education, Vehicle Motion Mechanics, Project-Based Learning

INTRODUCTION

Vocational education serves as a link between the academic world and industrial needs, thus playing an important role in producing a skilled workforce relevant to the demands of the modern economy (Billett, 2011; Pavlova, 2024). However, in Indonesia, its effectiveness remains hampered, as evidenced by the high unemployment rate among diploma graduates, which has decreased to 4.83% in 2024 (BPS, 2025). In the 21st century, vocational education must develop critical thinking and problem-solving skills—two main competencies that require reflective, analytical, and systematic approaches (Mulyasa, 2014).

Initial observations in the Vehicle Motion Mechanics course at Padang State University revealed several problems: the dominance of lecturer-centered learning, students' difficulty visualizing abstract mechanics concepts, a lack of connection between material and real-world contexts, and low critical thinking and problem-solving skills in analyzing vehicle systems (Daryanto & Raharjo, 2012; Falaq et al., 2023; Griffin et al., 2012; Hsieh et al., 2025). The development of artificial intelligence (AI) offers solutions through learning personalization, adaptive scaffolding, and interactive visualization (Putra et al., 2025; Çela et al., 2025). Claude supports the reinforcement of analytical reasoning, while Pollo AI provides dynamic visualization to help students understand complex mechanics concepts (Suparyati et al., 2023: Syamsara & Widiastuty, 2024; Zhou & Zhou, 2024).

However, research gaps persist, particularly regarding the integration of AI in vocational engineering learning, simultaneous studies of critical thinking and problem-solving, the use of mixed-methods approaches, and the development of constructivism-based pedagogical models integrated with AI. This study aims to fill these gaps by examining the influence of AI integration in the Project-Based Learning (PjBL) model on Vehicle Motion Mechanics learning to improve vocational students' critical thinking and problem-solving skills. The research findings are expected to strengthen theoretical studies while providing practical directions for transforming vocational education in the digital era.

METHOD

This study applied a quantitative experimental approach with a pre-experimental intact group comparison design. This design utilizes two natural groups (classes that have already been formed) as experimental groups and control groups. The experimental group received treatment in the form of AI integration, while the control group learned using a conventional approach without AI integration.

The research participants totaled 37 third-semester students who took the Vehicle Motion Mechanics course at the Department of Automotive Engineering Education, Faculty of Engineering, Padang State University, in the 2025/2026 academic year. With the total sampling technique, all students were divided into experimental groups (Class A, n=18) that received AI-based PjBL learning, and control groups (Class B, n=19) that followed conventional Discovery Learning with Case-Based Method without AI. Both groups have comparable academic characteristics, including educational background and meeting of course prerequisites.

Independent variables included the integration of AI (Claude and Pollo AI) through the PjBL model in the experimental group compared to conventional learning in the control group. Dependent variables include critical thinking skills measured using six indicators of Facione (1990) interpretation, analysis, evaluation, inference, explanation, and self-regulation as well as problem-solving skills based on six stages of Jonassen (2000): problem representation, analysis, development of alternative solutions, solution evaluation, implementation, and reflection.

The research instrument is in the form of a portfolio assessment sheet with an analytical rubric to measure critical thinking and problem-solving. The instrument was validated through expert judgment by three experts automotive engineering education experts, research methodology experts, and assessment experts as well as a limited trial with 30 previous batch of students. Validity was assessed using Aiken's Coefficient V ($V \geq 0.80$ indicates high validity), while reliability was tested using Cronbach's Alpha ($\alpha \geq 0.80$ indicates strong reliability). The validation and reliability results confirm that the instrument is feasible to use in the study.

This research was carried out from October to December 2025 through three main stages. The preparatory phase in October included instrument validation, initial training for experimental groups on the use of AI platforms (Claude and Pollo AI), and the formation of a project team. Furthermore, the implementation phase took place in November, where the experimental group received AI-integrated PjBL learning, while the control group followed conventional learning. At this stage, periodic assessments are carried out through three milestones, namely planning, implementation, and temporary presentation. The finalization phase in December included a comprehensive assessment of the project's final product, the conduct of in-depth structured interviews, and documentation analysis to assess the overall achievement of students.

Data were analyzed using descriptive statistics to describe the distribution of data, the Kolmogorov–Smirnov and Shapiro–Wilk normality tests, and the variance homogeneity test through the Levene's Test. Average comparisons between groups were made using independent samples t-test if parametric assumptions were met or Mann–Whitney U test if assumptions were not met. Effect sizes were calculated using Cohen's d, Hedges correction, and Glass's delta to assess the practical significance of the findings. All analyses were carried out with SPSS 26.0 at a significance level of $\alpha = 0.05$.

RESULTS AND DISCUSSION

Statistics Descriptive

Table 1 presents descriptive statistics for critical thinking and problem-solving skills in the experimental and control groups

Table 1. Descriptive Statistics of Research Variables

Variabel	Group	N	Average	SD	Min	Max
Critical Thinking	Eksperimen	18	82,45	6,23	72,00	93,00
	Control	19	71,33	7,89	58,00	84,00
Troubleshooting	Eksperimen	18	84,12	5,87	73,00	95,00
	Control	19	69,78	8,45	54,00	82,00

Table 1 shows the experimental group demonstrated a substantially higher average score in critical thinking (M=82.45; SD=6.23) and problem-solving (M=84.12; SD=5.87) compared to the control group (M=71.33; SD=7.89 and M=69.78; SD=8.45).

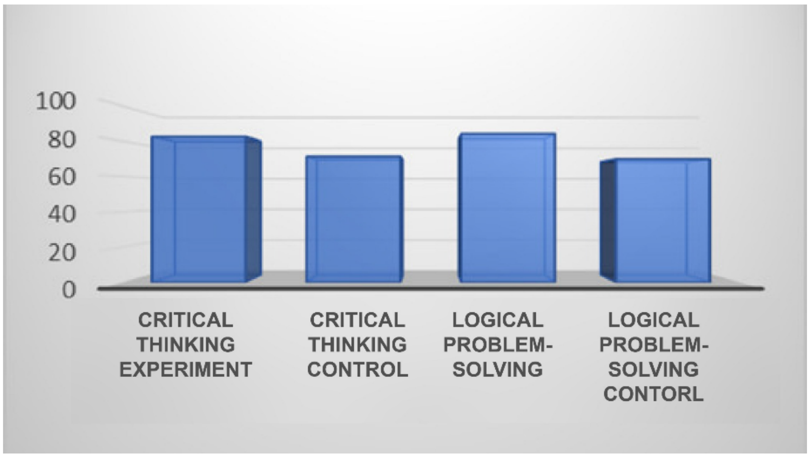

Figure 1. Skill Average Diagram

Figure 1 shows that on both critical thinking and problem-solving skills, the experimental group consistently obtained higher average scores than the control group. This visualization reinforces the descriptive finding that the treatment given to the experimental group contributed to the improvement of participants' abilities.

Prerequisite Test

Normality Test

The results of the Shapiro-Wilk test confirmed the entire distribution of normal variables ($p>0.05$): critical thinking of the experimental group ($p=0.186$), critical thinking of the control group ($p=0.142$), problem-solving of the experimental group ($p=0.234$), and problem-solving of the control group ($p=0.168$), meeting the assumptions of the parametric test.

Homogeneity Test

The results of Levene's Test indicated homogeneous variance between the groups for critical thinking ($F=2.34$; $p=0.135$) and problem-solving ($F=3.12$; $p=0.086$), confirming the assumption of similarity of variance for independent t-test samples.

Hypothesis Test

Critical Thinking Skills

Independent samples of t-test revealed significant differences in critical thinking skills between the experimental and control groups, $t(35)=4.67$; $p<0.001$. Experimental group ($M=82.45$; $SD=6.23$) had a significantly higher score than the control group ($M=71.33$; $SD=7.89$), with a mean difference of 11.12 points (95% CI [6.32; 15.92]).

Problem-Solving Skills

Similarly, problem-solving skills showed significant differences, $t(35)=5.89$; $p<0.001$. Experimental group ($M=84.12$; $SD=5.87$) substantially outperformed the control group ($M=69.78$; $SD=8.45$), with a mean difference of 14.34 points (95% CI [9.45; 19.23]).

Effect Size Analysis

The effect size calculation using Cohen's d demonstrates great practical significance for both variables (Table 2).

Table 2. Effect Size Analysis

Variabel	Cohen's d	Hedges' g	Glass's Δ	Interpretasi
Critical Thinking	1,52	1,48	1,41	Huge Effects
Troubleshooting	1,93	1,88	1,70	Huge Effects

Table 2 shows the entire effect size exceeding the Cohen (1988) threshold for large effects ($d \geq 0.80$), indicating the integration of AI through PjBL produces substantial practical impacts in developing critical thinking and problem-solving skills beyond statistical significance.

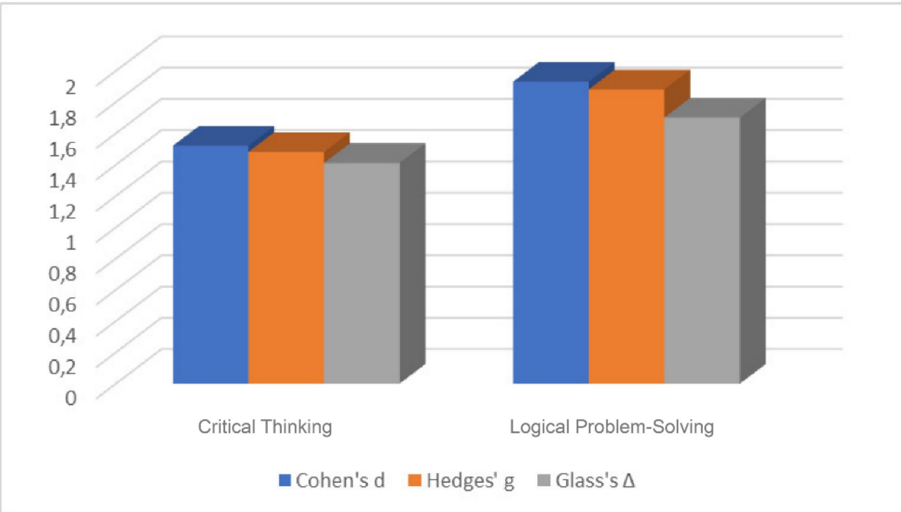

Figure 2. Diagram Effect Size

Figure 2 shows the consistency that all effect size sizes are in a very large range, both for critical thinking and problem-solving skills. This visualization further confirms that the implementation of PjBL-based AI integration has a strong and meaningful influence practically, not only statistically.

Qualitative Findings

AI Utilization Patterns

Observational data and interview analysis revealed that the students of the experimental group systematically utilized AI platforms: Claude AI for in-depth conceptual analysis, evaluating computational assumptions, receiving constructive feedback on solution strategies, and engaging in Socratic dialogues that encourage metacognitive reflection; Pollo AI to create dynamic Free Body Diagrams (FBDs), visualize load transfer during braking, simulate force distribution under various operational conditions, and generate prototyping concepts that integrate mechanical principles.

Development of Critical Thinking

Students demonstrate the improvement of critical thinking through: systematically interpreting complex vehicle specification data; analyze the causal relationship between mechanical variables (wheelbase, center of gravity, adhesion coefficient); evaluate the validity of assumptions in calculations; make valid technical inferences about the force distribution and efficiency of the system; explain the analytical process with strong conceptual justification; and self-regulation by monitoring and correcting thought processes when facing inconsistencies.

Improved Troubleshooting

Improved problem-solving is manifested through: creating a comprehensive FBD that accurately represents the forces on the vehicle system; formulate mathematical equations based on the principle of equilibrium; perform systematic calculations with high accuracy; evaluate the results against realistic physical conditions; draw valid technical conclusions (e.g., identifying which wheel is locking first); and communicate the solution process in a structured manner with good justification.

Student Perceptions

Qualitative interviews reveal positive perceptions: "Claude AI helped me understand why certain assumptions are important in calculations, not just how to calculate"; "Visualizing load transfer with Pollo AI makes abstract concepts concrete"; "Scaffolding AI allows me to work at my own pace while still being challenged"; "The combination of AI tools and a project-based approach makes learning more engaging and meaningful."

The Effects of AI Integration on Critical Thinking

The results showed that the integration of AI through the PjBL model significantly improved students' critical thinking skills ($d = 1.52$). These findings are consistent with Walter (2024), Lintner (2024), and Lawasi et al. (2024), who affirm the effectiveness of AI in supporting the development of critical thinking through adaptive scaffolding and providing opportunities for students to analyze, evaluate, and synthesize complex information. The magnitude of the effect size confirms that the increase is not only statistically significant, but also has a strong practical impact on students' analytical and evaluative abilities.

Claude AI's contribution to the improvement of critical thinking is in line with the findings of Syamsara and Widiastuty (2024) and Zhang and Pu (2025), which demonstrate Claude's ability to generate systematic explanations and structured responses as the foundation for strengthening analytical thinking. Dialogical interaction with Claude AI facilitates all components of critical thinking according to Facione (1990), including data interpretation, analysis of variable relationships, evaluation of arguments, inference, preparation of justified explanations, and self-regulation through metacognitive monitoring of thought processes.

Meanwhile, Pollo AI's visualization capabilities strengthen critical thinking through the mapping of abstract mechanics concepts into concrete visualizations that reduce external cognitive burdens. Dynamic representations of force distribution, load transfer, and aerodynamic effects allow students to study mechanical phenomena in more depth than static 2D representations. These findings support the research of Zhou and Zhou (2024) on the role of generative AI in improving conceptual understanding in vocational education.

The Effects of AI Integration on Problem Solving

AI integration showed a stronger impact on problem-solving skills ($d = 1.93$), providing empirical evidence that AI plays a significant role in systematically improving technical problem-solving capabilities. This research expands the framework of Jonassen (2000) by demonstrating how AI supports all stages of problem solving, starting from problem representation through visualization, analysis of problem components, development of alternative solutions, evaluation of options, implementation of procedures, to reflection on the effectiveness of the chosen solution.

A major improvement in this aspect shows that the power of the PjBL model in developing problem-solving competencies (Andri et al., 2025) is further strengthened by AI as adaptive scaffolding. AI-based personal support is in line with the principles of constructivism, especially the concept of the Zone of Proximal Development, where Claude AI functions as a more knowledgeable other that provides timely assistance, while Pollo AI acts as a cognitive tool to visualize problems more accurately.

Qualitative findings show that students are able to develop more mature problem-solving strategies such as the systematic preparation of Free Body Diagrams (FBD), the preparation of mathematical equations, the identification of constraints, the execution of calculations, and the validation of results. This comprehensive approach shows the formation of a deep conceptual understanding, not just procedural mastery, so that competencies can be transferred to new situations. This answers the challenge of vocational education in preparing adaptive graduates (Billett, 2011; Pavlova, 2024).

Synergistic Integration of AI and PjBL

The main contribution of this study lies in proving the synergistic effects that arise when AI is integrated with the PjBL model. While previous studies have tended to test the two separately, this study shows that the integration of the two creates a much stronger learning environment than if applied independently. PjBL provides an authentic and meaningful context for leveraging AI, making AI not just a computational tool, but a cognitive partner in knowledge construction. Instead, AI enriches the effectiveness of PjBL through instant feedback, adaptive scaffolding, dynamic visualization, and analytical support that cannot be obtained through conventional learning.

This synergy directly answers the long-standing problem of vocational education related to the quality and relevance of learning, as noted by Zukna and Sassi (2024) and Suhaedin et al. (2024). By simultaneously enhancing critical thinking and problem-solving through AI-based authentic projects, this model prepares students to face the demands of Industry 4.0 and Society 5.0 which demand technical competence as well as high-level thinking skills (Griffin et al., 2012).

Theoretical and Practical Implications

The findings of this study make an important theoretical contribution by strengthening Facione's (1990) critical thinking model, extending Jonassen's (2000) problem-solving theory, and providing empirical support for constructivist theory, especially the use of technology as a cognitive tool. From a practical perspective, these findings offer evidence-based guidelines for vocational educators in effectively integrating AI in learning, justifying institutional investments, and providing a scientific basis for the development of vocational education transformation policies in the digital age.

CONCLUSION

This study offers robust empirical evidence that integrating Artificial Intelligence (AI)—via Claude and Pollo AI—into Project-Based Learning significantly enhances critical thinking (Cohen's d=1.52) and problem-solving (Cohen's d=1.93) skills among automotive engineering students in the Vehicle Motion Mechanics course. The AI platforms effectively support all critical thinking components and problem-solving stages within authentic projects, creating a holistic learning ecosystem through synergistic analytical and visualization features that align with Industry 4.0 demands. Beyond theoretical advancements in critical thinking and problem-solving frameworks, the findings provide practical guidance for educators, institutions, and policymakers to accelerate vocational education's digital transformation. For future research, longitudinal studies could explore the long-term retention of these skills in professional settings and the scalability of this AI-PjBL model across diverse vocational disciplines.

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