

Artificial Intelligence-Based Project-Based Learning on Critical Thinking Skills: A Quasi-Experimental Study in Elementary School

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Abstract

This study aims to determine the influence of the *Artificial Intelligence (AI)*-based Project-Based Learning (PjBL) model on grade IV students' critical thinking abilities in science subjects at SDN Gentan. This study uses a *post-test only control group design*. The subjects of this study consisted of two groups: an experimental class that received an AI-based PjBL learning model and a control class that received a non-AI-based PjBL learning model. The instruments used in the study included multiple-choice tests to measure critical thinking skills and validated, reliable questionnaires. Data were analyzed using an *independent-samples t-test after meeting the prerequisite test*. The results showed a significant difference between the experimental and control classes, with a p-value of 0.003 ($< 0,05$), indicating that AI-based PjBL significantly improved students' critical thinking skills.

Keywords: *Project-Based Learning, Artificial Intelligence, Critical Thinking.*



A. INTRODUCTION

Rapid advances in information technology and globalization drive the transformation of education in the 21st Century. Every individual, regardless of educational level, will be faced with the use of digital technology and extensive access to information, therefore 21st-century abilities must be mastered. The American Association of Colleges for Teacher Education and Partnership for 21st Century Skills (P21) developed a framework for 21st-century skills that includes the 4Cs (critical thinking, creativity, collaboration, and communication) (Akhyar & Suryani, 2019) to help teachers facilitate students' 21st-century learning (Pratiwi, 2024).

Critical thinking is essential for 21st-century learning. Critical thinking involves interpretation, analysis, assessment, inference, explanation, and self-regulation, according to Facione (Putri et al., 2021). Students' critical thinking abilities help them examine, evaluate, and integrate knowledge for holistic development. Alessio et al. (2019). Elementary school students must develop critical thinking abilities early on. According to the theory of cognitive Development put forward by Piaget, the concrete operational phase that takes place between the ages of 7 and 11 is the time when children begin to develop critical and logical thinking skills. (Nurhayani & Salistina, 2022). Therefore, in learning, every student must develop the ability to think critically to understand concepts better, solve learning problems, and apply them in daily life.

However, the Trends in International Mathematics and Science Study (TIMSS) found that Indonesian students' critical thinking abilities rank 44th out of 49 nations with an average score of 397, well below the world average. (2025, Panjaitan & Simamora). Elementary school social studies education has a critical thinking issue. According to a 2022 Ministry of Education, Culture, Research, and Technology poll, just 47% of primary school teachers are confidence in using digital technology to teach social studies (Wardhani, 2025). The lack of variation in learning activities, such as the use of technology, prevents the optimal Development of critical thinking. To support this, teachers must be innovative and creative in designing media, models, and learning approaches so that all students can be physically and mentally involved during the learning process. (Wirawan et al., 2024).

Elementary school children' critical thinking abilities are inadequate, say experts. This is evident in their struggles to recognize issues, analyze data, generate solutions, and reach objective conclusions. In addition, the application of a learning model that does not emphasize active interaction with students makes students more likely to memorize concepts without doing critical reflection. As a result, students often have difficulty assessing arguments, concluding learning independently, and giving reasons by referring to the right cause and effect, especially in IPAS learning.

In essence, effective social studies learning is designed to develop critical thinking skills. IPAS learning has three main elements: IPAS as scientific knowledge, as a research process with scientific methods, and as a scientific attitude that includes openness, curiosity, and objectivity. In the process of learning social studies, students are guided to develop procedural skills in exploring nature, solving problems, and making logical assessments to deepen their conceptual understanding. (Alditia et al., 2024). Thus, social studies learning not only focuses on mastering knowledge, but also on developing critical thinking skills, such as analyzing, assessing, drawing conclusions, and making decisions based on evidence.

Project-Based Learning is an effective learning model for improving critical thinking skills. Several studies report that applying the PjBL model positively affects critical thinking skills (Astri et al., 2022; Panjaitan & Simamora, 2025; Wirawan et al., 2024). PjBL is a learning model that organizes student learning through a project. This learning model utilizes problems as a starting point for acquiring new knowledge and connecting it with practical experience. This process encourages students to analyze, make decisions, and reflect on learning outcomes, thereby encouraging their critical thinking skills. (Mutiarani & Farhurohman, 2024). Although effective, the PjBL model is often constrained by learning resources and teaching resources. (Andita & Kurniawati, 2024). For this reason, technology integration is relevant, as it can help overcome these limitations. AI helps tailor learning to learners' needs, increase learning productivity, and support the Development of critical thinking skills. (Cahyani & Nurdin, 2025; Mandayani & Haifaturrahmah, 2025; Usman et al., 2025).

Project-based learning combined with artificial intelligence (AI) can improve primary school learners' critical thinking skills by engaging them in real-world projects that encourage them to explore problems and work together to solve them. In

this process, AI provides customized feedback, customizes content, and directly supports data analysis. This incorporation is consistent with the constructivist theory initiated by Piaget and Vygotsky, which posits that learners actively develop their knowledge through real-world experiences in PjBL projects. At the same time, AI supports proximal developmental zones (ZPDs) with tailored guidance to develop analysis, synthesis, and evaluation abilities. (Alim & Butsiarah, 2025; Y Mones et al., 2023).

Although PjBL and AI have been shown to support the Development of critical thinking skills, empirical studies that integrate AI-based PjBL as a structured learning model in IPAS subjects on the topic of *Material, "What Creature Is It?"*, remain limited. Previous studies only highlighted the Development of PjBL at the project implementation stage and the implementation of PjBL without AI support. Optimizing AI integration in PjBL to increase students' critical thinking abilities is lacking in research. Thus, the goal of this research is to assess how the AI-based Project-Based Learning (PjBL) model affects grade IV SD Negeri Gentan students' critical thinking abilities.

B. METHOD

Research uses quasi-experimental post-test only control groups. The experimental class receives a PjBL-based AI model, whereas the control class gets PjBL learning without AI. The AI applied in this study is Perplexity AI. Perplexity AI is a search platform that can provide informative responses by including source references. (Nur et al., 2023). The use of AI focuses on the investigation and exploration phases of the project, where students receive conceptual explanations and independently compare information across various sources.

The population in this study is all grade IV students of State Elementary Schools in the Gentan cluster. Sampling technique using *cluster random sampling*, i.e., sample selection based on the class that has been formed (Sugiyono, 2018). Research samples were two classes chosen at random. In this research, grade IV students from SDN Gentan 1 and 3 were the control and experimental classes. According to school class sizes, the control class comprised 10 pupils and the experimental class 31.

This study measures critical thinking abilities using multiple-choice tests and learning reflection questionnaires to reinforce research outcomes. The results of the empirical trial analysis stated that 11 questions were valid. The instrument's reliability coefficient of 0.913 indicates a high level of internal consistency. The exam measures Facione's interpretation, analysis, evaluation, inference, explanation, and self-regulation (Putri et al., 2021).

Table 1. Indicators of Critical Thinking Ability

Number	Indicator	Remarks
1	Interpretation	The ability to understand and explain the meaning or significance of various experiences, situations, data, or concepts.
2	Analysis	The ability to identify inferential relationships (inferences) between statements, questions, concepts, or descriptions.

3	Inference	Ability to draw logical conclusions, form conjectures, and consider relevant information.
4	Evaluation	The ability to assess the credibility of statements or representations of inferential relationships.
5	Explanation	Justify the scientific procedure or reason that supports the answer.
6	Self-regulation	The ability to monitor, check, and correct one's own thought process so that the decisions taken are correct and accountable.

Before the hypothesis test, Shapiro-Wilk normality and Levene homogeneity tests were performed. The Independent Samples t-test in SPSS version 25 tested the hypothesis that posttest data indicated a 0.05 significant difference in average critical thinking abilities between experimental and control courses. This study provides two hypotheses: H_0 : no difference in critical thinking skills between experimental and control courses, and H_1 : a difference. Relevance drives decisions. The AI-based Project-Based Learning (PjBL) model substantially influences students' critical thinking skills, as shown by Sig. (2-tailed) < 0.05 .

C. RESULTS AND DISCUSSION

Descriptive statistical analysis aims to provide an overview of the post-test results for the control and experimental classes. This analysis includes the minimum, maximum, mean, and standard deviation to identify data patterns and differences between the two groups. (Deva Martias, 2021). In addition, normality and homogeneity tests were performed as a prerequisite for analysis.

Table 2. Results of Descriptive Statistical Tests and Prerequisite Tests

Variable	Min	Max	Mean	SD	Sig. Shapiro Wilk	df	Sig. Levene
Post-test Control	18	91	59.90	18.97	0.192	10	0.295
Post-test Experiment	54	100	75.67	11.87	0.053	31	0.295

We ran Shapiro-Wilk normality and Levene homogeneity tests before the hypothesis test. The SPSS version 25 Independent Samples t-test examined the hypothesis that post-test data showed a 0.05 significant difference in average critical thinking between experimental and control courses. This research proposes two hypotheses: H_0 : no change in critical thinking abilities between experimental and control courses, and H_1 : a difference. Decisions depend on relevance. Sig. (2-tailed) < 0.05 rejects H_0 and accepts H_1 , proving the AI-based PjBL model's strong influence on students' critical thinking, indicating that the variances of the two groups were homogeneous. Thus, the parametric test assumptions have been met.

This research employed an independent-samples t-test based on the post-test value of the control class with trials to test the null hypothesis H_0 : The critical thinking and PjBL therapy without AI and the AI-based treatment were not significantly different. A considerable difference exists between critical thinking and AI-based PjBL therapy and non-AI-based. If Sig. < 0.05 , H_0 is rejected and H_1 is approved. H_0 is accepted and H_1 rejected if > 0.05 . The SPSS 25 independent t-test results were.

Table 3. Independent Sample t-Test Results

Classes	Mean	t	df	Sig. (2-tailed)	95% C.I. Lower	95% C.I. Upper
Control	59.90	-3.134	39	0.003	-25.95	-5.59
Experiment	75.67					

The Table above shows that the control class has a mean of 59.90 and the experimental class 75.67. A Sig too. The 0.003 value rejected H0 and accepted H1, suggesting a significant difference between the critical thinking and PjBL therapy without AI and the AI-based PjBL treatment ($p < 0.05$).

The questionnaire instrument used a Likert scale of 1–5, which consisted of the categories Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). The distribution of respondents' statement item percentage replies was determined via descriptive analysis. Table shows distribution findings.

Table 4. Distribution of Respondent Answer Percentage

No	Item	STS (%)	TS (%)	N (%)	S (%)	SS (%)	Total (%)
1	The use of AI in project learning helped me understand lesson concepts better	0.0	0.0	9.7	41.9	48.4	100
2	Through AI-based project learning, I am more active in finding information and solutions in classroom learning	0.0	0.0	19.4	51.6	29.0	100
3	AI helps analyze project data, making the learning process more efficient	0.0	3.2	22.6	41.9	32.3	100
4	I can identify key issues in AI-assisted projects	3,2	6,5	3,2	61,3	25.8	100
5	I can evaluate the information from the AI before it is used in creating a project	3.2	0.0	22.6	54.8	19.4	100
6	I was able to provide a logical reason for my AI-media-assisted project solution	0.0	6.5	12.9	51.6	29.0	100
7	I compare different solutions before choosing the best one	0.0	6.5	9.7	51.6	32.3	100
8	I think logical errors in data or suggestions from AI	0.0	3.2	12.9	61.3	22.6	100
9	I reflect on the results of the project for future improvements	0.0	0.0	19.4	45.2	35.5	100
10	My critical thinking improved after participating in an AI-assisted project learning	0.0	0.0	6.5	32.3	61.3	100

Based on Table 4, the questionnaire results showed that the majority of students answered in the Agree (S) and Strongly Agree (SS) categories, with the highest percentage at 61.3% for the 10th item. In comparison, the response to Strongly Disagree (STS) was relatively low, with a maximum percentage of 3.2%. This distribution matches post-test findings, indicating that AI-based PjBL improves students' critical thinking.

A descriptive statistical analysis indicated the post-test score difference between groups. The experimental class (75.67) had a 15.77-point higher average post-test score than the control class (59.90), demonstrating that AI-based PjBL increases critical thinking. The experimental class had a more equal score distribution since its

standard deviation was 11.87 compared to 18.97 for the control class. The hypothesis test by Independent Sample t-test (Table 3) revealed a significant difference between the two groups ($p = 0.003 < 0.05$). AI assistance in PjBL improves critical thinking abilities compared to PjBL without AI help.

The experimental class increased significantly, according to Facione's critical thinking theory, which comprises interpretation, analysis, evaluation, inference, explanation, and self-regulation (Putri et al., 2021). AI in PjBL helps students assess information, evaluate alternatives, and organize explanations. The constructivist theory of Piaget and Vygotsky matches this study's results. Piaget states that children at primary school age are at the stage of concrete operations, where learning that focuses on direct experience is very helpful in improving critical thinking skills (Nurhayani & Salistina, 2022). PjBL provides concrete experiences through real projects, while AI integration acts as a *scaffolding* digital that supports the Proximal Development Zone (ZPD) as explained by Vygotsky, so that the integration of AI in PjBL allows students to obtain adaptive feedback, access relevant information, and conduct data-driven reflections during the project work process (Y Mones et al., 2023).

Pedagogically, the learning process in AI-based PjBL takes place through several stages. First, students identify the problems of the given project, then utilize AI to obtain initial information, verify ideas, and explore various solution options. The results of the exploration are discussed in groups, allowing negotiation of meaning and strengthening of arguments. The teacher functions as a facilitator who directs the validity of the information and the depth of the students' analysis. The integration of collaborative learning and adaptive technology support can improve the ability to analyze, evaluate, and draw conclusions more effectively than AI-assisted PjBL learning. (Wibowo et al., 2026).

This research confirms prior findings that PjBL improves critical thinking (Astri, 2022; Panjaitan & Simamora, 2025; Wirawan, 2024). Mandayani & Haifaturrahmah (2025), and Alim & Butsiarah (2025) have shown that AI helps increase critical thinking in learning. This work stands out for integrating PjBL and AI in elementary school science learning and using an experimental methodology that directly contrasts PjBL with and without AI.

This research reveals that AI-based PjBL improves elementary school critical thinking using data. This study suggests that instructors may utilize AI to guide project-based learning by asking triggering questions, strengthening digital literacy, and offering direction on assessing the accuracy of information. With a good learning process, AI integration has the potential to lead to more reflective IPAS learning, aligned with technological advancements and the skills needed in the 21st Century.

D. CONCLUSION

This research found that the AI-based Project-Based Learning (PjBL) paradigm improves scientific students' critical thinking. The Independent Sample t-test findings indicate a significant difference (p -value < 0.05) and a larger average score gain in the experimental class compared to the control class. Theoretically, the results of this

study support the constructivist theories of Piaget and Vygotsky, as well as the Facione critical thinking framework, in which the integration of AI in PjBL serves as digital scaffolding that encourages students' analysis, evaluation, reflection, and self-regulation. Using AI in PjBL increases elementary school pupils' critical thinking abilities for the 21st century.

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