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Implementation of Problem-Based Mathematics Learning in Improving Critical Thinking Skills

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ABSTRAK

Critical thinking skills are one of the important competencies of the 21st century that need to be developed through mathematics learning. However, conventional learning practices in the classroom often still emphasize procedural memorization, so students are less trained in analyzing and evaluating contextual problems. This study aims to analyze the effectiveness of the implementation of Problem-Based Learning (PBL) assisted by digital media in improving students' mathematical critical thinking skills. The study used a quantitative approach with a quasi-experimental non-equivalent control group design. The subjects of the study involved 64 junior high school students, who were divided into experimental classes (PBL + digital media) and control classes (conventional learning). The instruments used included critical thinking skills tests (pre-test and post-test), observation sheets, and student perception questionnaires. The results showed that the average post-test score of the experimental class was higher than that of the control class with an N-Gain value of 0.61 (medium category), while the control class only reached 0.32 (low category). The t-test showed a significant difference at the level of 0.05. Observations and questionnaires support these findings, where students feel more motivated, interactive, and confident in learning. In conclusion, PBL assisted by digital media has proven to be effective in improving students' mathematical critical thinking skills and creating a more meaningful and collaborative learning atmosphere.

INTRODUCTION

21st century education requires students to have higher order thinking skills, where critical thinking skills are an important foundation in facing global challenges. These skills not only allow students to analyze information, but also to evaluate arguments, make rational decisions, as well as solve complex problems that often do not have one right answer. In the context of mathematics learning, critical thinking skills are very important because mathematics demands logical, deductive, and reflective thinking processes. Nevertheless, learning practices in schools still show a strong tendency towards conventional approaches that emphasize procedure and memorization rather than conceptual reasoning. As a result, students are used to solving routine problems, but have difficulty dealing with non-routine problems that require more in-depth

analytical skills (Darhim, Prabawanto, & Susilo, 2020; Widyatiningtyas, Kusumah, Sumarmo, & Sabandar, 2015).

This phenomenon is in line with the results of international surveys such as the Programme for International Student Assessment (PISA) which shows that the mathematical ability of Indonesian students is still low, especially in indicators related to critical thinking skills and contextual problem solving. Many students tend to rely on formulas without understanding the logical process behind them. As a result, they find it difficult when faced with real problems that require creative and evaluative solution strategies (Yolanda, 2019). This situation indicates a mismatch between the demands of the national curriculum that emphasizes the development of HOTS and daily learning practices that are still teacher-centered. Therefore, an alternative learning model is needed that is able to shift the learning paradigm from simply memorizing formulas to critical and reflective thinking activities. One of the learning models that is widely considered relevant is Problem-Based Learning (PBL). PBL places real problems as the starting point of learning, where students are encouraged to identify problems, formulate hypotheses, gather information, test solutions, and reflect. Through these stages, students not only acquire new knowledge, but also practice critical thinking skills in a structured manner (Hmelo-Silver & Eberbach, 2021). In mathematics learning, PBL is believed to be able to help students connect abstract concepts with real applications, making them more meaningful. A number of studies have shown that the application of PBL can improve students' mathematical critical thinking skills compared to conventional learning (Suparman, Juandi, & Tamur, 2021; Zulkarnain, Syaiful, & Suratno, 2023).

However, research results on the effectiveness of PBL are not always consistent. A meta-analysis conducted by Suparman et al. (2021) showed that PBL had a significant positive influence on critical thinking skills, but the variation in effects was considerable depending on the study design, duration of intervention, and learning context. A similar thing was expressed by Liu and Pásztor (2022) who found that the effectiveness of PBL in higher education is greatly influenced by the quality of instruction and the role of facilitators. This study indicates that although PBL has great potential, its success is largely determined by implementation factors. Thus, there is a research gap in understanding how PBL can be optimized in the context of mathematics learning in Indonesia. The research gap is also seen in the lack of studies that integrate technology or supporting media in the implementation of PBL. The study of Mudrika, Syaifuddin, and Azmi (2024) shows that the use of interactive media such as Wordwall can strengthen the implementation of PBL by increasing student motivation and involvement, thereby indirectly supporting critical thinking skills. Similarly, research by Suardika, Pujawan, and Divayana (2024) found that the use of interactive animated videos in PBL was able to strengthen students' problem-solving and critical thinking skills in mathematics learning. However, similar research is still very limited in Indonesia, even though the integration of digital technology is in line with the demands of 21st century learning.

In addition, most PBL research focuses more on short-term impacts, while studies on the long-term sustainability of critical thinking skills are rare. Lu (2025) through a meta-analysis confirms that although PBL consistently improves critical thinking, the evidence on its long-term impact is still weak and requires further study. In line with that, Ge (2025) in a literature review found that the sustainability of students' critical skills is highly dependent on the consistency of PBL implementation and the

support of continuous reflection. This gap is important to answer because critical thinking is not a skill that can be acquired instantly, but through a long process that is integrated into various learning experiences. Criticism of PBL also arises from a methodological perspective. Thorndahl and Stentoft (2020) in a scoping review emphasize that although PBL is effective, many studies have not explicitly defined the indicators of critical thinking that are measured. As a result, it is difficult to draw comprehensive conclusions regarding the effectiveness of PBL. In Indonesia, a similar thing happens when teachers implement PBL without a deep understanding of its basic principles. This causes the implementation of PBL to be limited to providing story questions without involving the stages of exploration and critical reflection that should exist. Research by Cantona, Suastra, and Ardana (2023) proves that PBLs designed with HOTS orientation can significantly improve the critical thinking skills of elementary school students, confirming the importance of proper instructional design.

By considering the results of the above research, several main research gaps can be identified. First, the effectiveness of PBL in mathematics learning still varies and requires further study of the factors that affect it. Second, the integration of media and technology in PBL is still limited, even though it has the potential to strengthen students' critical thinking skills. Third, most studies focus only on short-term impacts, while longitudinal studies on the sustainability of critical thinking skills are rare. Fourth, indicators of critical thinking are often poorly defined in research, making it difficult to compare the results. Fifth, the local context in Indonesia, such as the limited understanding of teachers and heterogeneous classroom conditions, has also not been studied in depth.

The novelty of this research lies in the comprehensive approach in examining the implementation of PBL in mathematics learning by paying attention to three important aspects. First, this study integrates digital supporting media to strengthen the PBL process so that it is more effective in training critical thinking skills. Second, this research focuses on clearly defined indicators of critical thinking, such as the ability to identify problems, evaluate arguments, test solutions, and reflect. Third, this study places the Indonesian educational context as the main focus, so that the results are expected to make a relevant theoretical and practical contribution to the development of mathematics learning in schools. Based on the phenomena, gaps, and novelties that have been described, the purpose of this study is to analyze the implementation of Problem-Based Learning in mathematics learning by paying attention to the role of digital supporting media and the Indonesian educational context in improving students' critical thinking skills. Thus, this research is expected to strengthen the empirical evidence on the effectiveness of PBL and provide practical recommendations for teachers in designing mathematics learning that is more innovative and in line with the demands of the 21st century.

METHODOLOGY

This study uses a quantitative approach with a quasi-experimental non-equivalent control group design involving two parallel classes at the junior high school level in Indonesia, each totaling 32 students for a total sample of 64 students. The experimental class was treated with a Problem-Based Learning (PBL) model assisted by digital media in the form of interactive question cards and animated videos, while the control class was taught with conventional methods based on lectures and practice

questions. The PBL learning toolkit is designed based on the main syntax of PBL, validated by experts, and tested on a limited basis before being implemented in six meetings. The data collection technique was carried out with three main instruments: (1) a mathematical critical thinking skill test based on the Ennis indicator which was given as a pre-test and post-test, (2) an observation sheet to record the implementation of PBL syntax and student activities, and (3) a perception questionnaire with a five-point Likert scale to explore students' views on the effectiveness of PBL assisted by digital media in supporting critical thinking skills.

The collected data was analyzed by combining quantitative and qualitative techniques. The test results were analyzed through prerequisite tests (normality and homogeneity) then followed by independent samples t-test to measure the average difference in critical thinking ability between the experimental and control classes. In addition, the normalized gain (N-Gain) calculation is used to assess the level of improvement in critical thinking skills in more detail. Questionnaire data were analyzed descriptively to map the distribution of student perceptions, while observational data were reduced, presented, and interpreted to support quantitative findings. Data triangulation is carried out by combining test results, observations, and questionnaires to ensure the validity and richness of the interpretation of the findings. Through this design, the research is expected to be able to provide a comprehensive overview of the effectiveness of the implementation of digital media-based PBL in improving students' critical thinking skills, as well as uncovering the factors that support and hinder its success in the context of mathematics education in Indonesia.

RESULTS AND DISCUSSION

Table 1. Descriptive Statistics of Critical Thinking Skills Test Results

Class	N	Average Pre-test	Post-test average	SD Pre-test	SD Post-test	N-Gain	Category
Experiment (PBL + digital media)	32	45.63	78.75	8.21	7.54	0.61	Keep
Control (Conventional)	32	44.97	63.28	7.98	8.10	0.32	Low

Remarks: N-Gain is categorized according to Hake (low <0.3, medium 0.3–0.7, high >0.7).

The results in Table 1 show that the average pre-test score between the experimental class (45.63) and the control class (44.97) is relatively similar, so it can be assumed that both groups have equal initial mathematical critical thinking skills. After treatment, the average post-test of the experimental class increased to 78.75 with a standard deviation of 7.54, while the control class only reached an average of 63.28 with a standard deviation of 8.10. The increase that occurred in the experimental class was also reflected in the normalized gain (N-Gain) value of 0.61 which was in the medium category, while the control class only obtained an N-Gain of 0.32 in the low category.

Table 2. Independent Samples t-test Test Post-test Results

Variable	Experimental Class (M±SD)	Control Class (M±SD)	t-value	Df	Sig. (2-tailed)	Decision

Critical Thinking Skills	78.75 ± 7.54	63.28 ± 8.10	6.82	62	0.000	Significant

Remarks: The results of *the t-test* showed a significant difference in the average of students' critical thinking skills between the experimental and control classes at the level of 0.05 ($p < 0.05$).

The results of the analysis of independent t-test samples in Table 2 show that there is a significant difference between the post-test scores of the experimental class (78.75 ± 7.54) and the control class (63.28 ± 8.10), with a t-value of 6.82 and a significance of 0.000 ($p < 0.05$). This shows that the PBL model assisted by digital media has a real influence on improving students' critical thinking skills. Thus, the research hypothesis that there is a significant difference between classes taught using PBL and classes taught conventionally is acceptable.

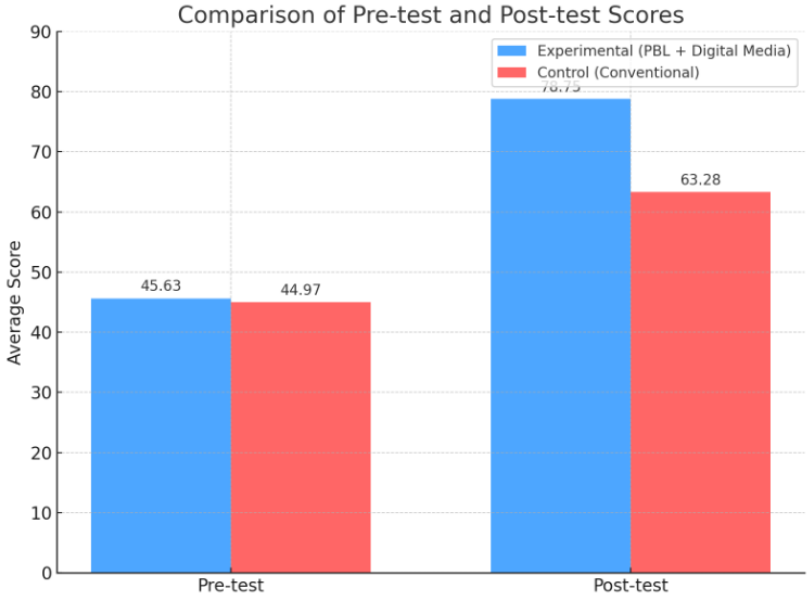
Table 3. Recapitulation of Student Perception of PBL Survey Results

Statement	Strongly Agree (%)	Agree (%)	Neutral (%)	Disagree (%)	Strongly Disagree (%)
PBL helped me understand math concepts more deeply	43.8	40.6	12.5	3.1	0.0
Digital media makes learning more engaging and interactive	53.1	34.4	9.4	3.1	0.0
Group discussions in PBL train critical thinking skills	46.9	37.5	12.5	3.1	0.0
I feel more confident in expressing my opinion after studying with PBL	37.5	43.8	15.6	3.1	0.0

Table 3 shows that the majority of students responded positively to the implementation of PBL assisted by digital media. The results of the questionnaire strengthened the quantitative data, where the majority of students responded positively to PBL, especially in helping concept understanding, increasing interactivity, and training the courage to think critically through group discussions. As many as 84.4% of students agree or strongly agree that PBL helps them understand math concepts more deeply, and 87.5% of students feel that digital media makes learning more interesting and interactive. In addition, 84.4% of students rated group discussions in PBL as effective in practicing critical thinking skills, and 81.3% of students admitted to being more confident in expressing their opinions after participating in learning with the PBL model. These results indicate that PBL not only has an impact on improving quantitative learning outcomes, but also creates a more participatory learning atmosphere and motivates students to be active.

The results of this study show that the implementation of Problem-Based Learning (PBL) assisted by digital media has a significant impact on improving students' mathematical critical thinking skills. The pre-test data showed that the initial

ability between the experimental class and the control class was relatively equivalent. However, after treatment, the average post-test score of students in the experimental class was higher with an N-Gain value of 0.61 (medium category), while the control class only obtained 0.32 (low category).



The graph shows the comparison of the average pre-test and post-test scores between the experimental classes taught with Problem-Based Learning (PBL) assisted by digital media and the control classes taught conventionally. At the time of the pre-test, both classes had relatively the same initial ability, namely 45.63 for the experimental class and 44.97 for the control class. However, after treatment, there was a significant increase in the experimental class with an average post-test score of 78.75, while the control class only reached 63.28. A greater increase in experimental classes showed that the application of PBL assisted by digital media was more effective in developing students' mathematical critical thinking skills compared to conventional learning. This is in line with the results of the t-test and the N-Gain value that have been analyzed previously, which both confirm the significant influence of the implementation of PBL assisted by digital media on improving students' critical thinking skills.

In addition, the results of the t-test on the post-test score showed a significant difference with a p< value of 0.05, which means that the application of PBL with digital media significantly improves critical thinking skills compared to conventional learning. These findings are consistent with the results of a meta-analysis by Juandi and Tamur (2021) which show that PBL has a significant influence on improving mathematical thinking skills, including critical thinking. The meta-analysis confirms that when students are faced with authentic problems, they are encouraged to engage in analysis, evaluation, and reflection that are at the core of critical thinking skills. The same thing is also shown by Sari and Dhoruri (2024) through quasi-experimental research, that students who study with the PBL model show better critical thinking skills compared to students who are taught traditionally.

PBL essentially puts students in problematic situations that demand active involvement. The process starting from problem identification, hypothesis submission, information search, to solution evaluation is in line with the indicators of critical thinking according to Ennis, namely clarification, inference, evaluation, and reflection.

Gijbels et al. (2005) assert that the advantages of PBL are evident when the assessment is directed at understanding concepts and applications in new situations, rather than just procedural memorization. This research supports this argument because the tests used measure mathematical analysis and evaluation skills, so that the experimental class is superior to the controls. The results of learning observations also show that students in the experimental class are more active in discussing, presenting arguments, and evaluating the proposed solutions. This is in line with the findings of Indriani, Isnarto, and Mariani (2019) who reported that the application of PBL with educational game media not only increases critical thinking skills, but also students' confidence in expressing opinions. With the existence of digital media in the form of question cards and animated videos, the interaction in the experimental classroom becomes more lively, so that students have the space to explore ideas and assess arguments more deeply.

Students' positive perceptions of learning also support quantitative outcomes. Most students stated that PBL with digital media helped them understand mathematical concepts more deeply, increase interactivity, and foster confidence. The study of Zaini, Yusuf, and Halim (2022) also found that PBL not only has an impact on critical thinking skills, but also improves scientific literacy and students' positive attitudes towards learning. These findings confirm that the benefits of PBL are not only limited to improving test results, but also to the formation of a constructive learning attitude. The use of digital media in this study has been proven to be a factor that strengthens the effectiveness of PBL. Evendi (2022) found that e-PBL in mathematics learning is more effective in improving critical thinking skills than conventional PBL because digital media provides visual representation, interactivity, and quick feedback. The same thing is affirmed by Marthaliakirana, Suwono, Saefi, and Gofur (2022) who found that the use of metacognitive prompts in PBL is able to significantly improve students' argumentation and critical thinking skills. Thus, digital media support in PBL acts as a scaffolding that strengthens students' thinking processes.

These findings also show consistency with global studies. Meta-analysis of Dochy, Segers, Van den Bossche, and Gijbels (2003) concluded that PBL excels in improving long-term retention, concept comprehension, and critical thinking skills compared to conventional learning. Nonetheless, they emphasized that the success of PBL is heavily influenced by the design of the problem and the quality of teacher facilitation. This is reflected in this study, where the implementation of PBL syntax is well observed, so that the results are significant. From a local perspective, research by Samura, Juandi, and Darhim (2020) on Indonesian students shows that PBL improves mathematical critical thinking skills better than conventional models. The results of this study are in line with Syaiful, Zulkarnain, and Suratno (2023) who reported that the application of PBL to the Pythagorean Theorem material resulted in a significant increase in the critical thinking skills of junior high school students. The consistency of results from various levels of education in Indonesia strengthens the belief that PBL is relevant and effective in the context of the national curriculum. In addition, the research of Siregar, Nasution, and Zulfahmi (2023) added that PBL not only improves critical thinking skills, but also students' motivation to learn. This is reflected in this study through questionnaire data, where students stated that they were more motivated and felt that learning was more interesting with the integration of digital media. Increased motivation serves as an internal driver to actively participate in the PBL process, which ultimately strengthens critical thinking skills.

Nevertheless, the effectiveness of PBL still depends on several factors. Walker and Leary (2009) through meta-analysis showed that the variation in implementation, problem type, and form of assessment affected PBL results. Strobel and van Barneveld (2009) also assert that PBL is superior in mastery of long-term concepts, but short-term outcomes are sometimes not much different from traditional learning. Therefore, the significant difference in post-test scores in this study may be due to an assessment design that emphasizes high-level reasoning rather than procedural memorization. In the context of the Indonesian curriculum, these findings provide important practical implications. Ahdhianto, Marsigit, Haryanto, and Nurfauzi (2020) show that the application of PBL in elementary schools is able to improve problem-solving skills as well as critical thinking. This proves that PBL can be adapted to various levels of education with consistent results. With the addition of digital media, the effectiveness is even higher because students can visualize abstract problems more realistically. Thus, this discussion confirms that the research objective was achieved: PBL assisted by digital media has been proven to be more effective in improving students' critical thinking skills compared to conventional learning. This increase can be seen both from test results and student perceptions. The support of the global and local literature provides a strong empirical foundation that PBL is relevant to be applied in mathematics learning in Indonesia.

CONCLUSION

This study demonstrates that Problem-Based Learning (PBL) assisted by digital media effectively enhances students' mathematical critical thinking skills. The experimental class achieved higher post-test scores and a medium N-Gain, while the control class remained in the low category. The t-test confirmed significant differences between the two groups, proving that integrating PBL with interactive question cards and animated videos contributes to students' ability to analyze, evaluate, and reflect on mathematical problems. Moreover, it fosters a more interactive, collaborative, and motivating learning environment, fulfilling the research objective comprehensively.

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