

Implementing the Project-Based Learning Model to Enhance Students' Critical Thinking Skills at SMP Negeri 29 Makassar

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Abstract

Critical thinking skills are essential competencies in mathematics education, enabling students to analyze problems, evaluate information, and construct logical arguments. However, students' critical thinking abilities are often underdeveloped due to the dominance of teacher-centered instructional practices. This study aims to examine the effectiveness of the Project-Based Learning (PjBL) model in enhancing students' critical thinking skills in mathematics at SMP Negeri 29 Makassar. This research employed a quantitative approach using a quasi-experimental design with a one-group pretest–posttest model. The participants consisted of 32 students. Data were collected through a critical thinking test administered before and after the implementation of the PjBL model. The data were analyzed using descriptive statistics, normality and homogeneity tests, paired sample t-test, and N-Gain analysis. The results revealed a significant improvement in students' critical thinking skills. The mean score increased from 62.34 in the pretest to 84.12 in the posttest. The paired sample t-test showed a statistically significant difference ($p < 0.05$), indicating the effectiveness of the intervention. Furthermore, the N-Gain value of 0.58 was categorized as moderate, suggesting a meaningful level of improvement. These findings indicate that the implementation of the Project-Based Learning model effectively enhances students' critical thinking skills by promoting active engagement, collaboration, and reflective learning. Therefore, PjBL can be considered a suitable instructional approach for fostering higher-order thinking skills in mathematics education.

Keywords: Project-Based Learning, Critical Thinking Skills, Mathematics Education.



INTRODUCTION

Critical thinking skills have become one of the most essential competencies in 21st-century education, particularly in mathematics learning (Arianti Masanggelo et al., 2024). In an era characterized by rapid technological development, complex problem-solving demands, and the abundance of information, students are required not only to acquire knowledge but also to analyze, evaluate, and apply that knowledge in meaningful ways. Critical thinking enables students to interpret problems, identify relevant information, assess alternative solutions, and make logical decisions based on evidence. In mathematics education, this skill plays a central role, as mathematical learning inherently involves reasoning, abstraction, and structured problem solving (Nasir & Liani, 2025; Toikka et al., 2024). Mathematics is not merely a collection of formulas and procedures but a discipline that emphasizes logical thinking, analytical reasoning, and the ability to construct and justify arguments. Therefore, developing students' critical thinking skills in mathematics is a fundamental goal of education. Students who possess strong critical thinking abilities are better equipped to understand mathematical concepts, solve non-routine problems, and apply their knowledge to real-life situations. They are also more capable of evaluating the correctness of their solutions and reflecting on their reasoning processes (Fadli et al., 2022; Sachdeva & Eggen, 2021; Sappaile, Wahyudin, et al., 2025).

However, despite its importance, the development of critical thinking skills in mathematics classrooms remains a significant challenge. In many educational settings, including secondary schools, teaching practices are still dominated by teacher-centered approaches. Instruction often focuses on procedural fluency, where students are trained to follow steps and memorize formulas without fully understanding the underlying concepts. As a result, students tend to become passive learners who rely heavily on teachers' explanations and struggle when faced with unfamiliar or complex problems. This issue is particularly evident in students' inability to engage in higher-order thinking processes such as analysis, evaluation, and synthesis. Many students find it difficult to interpret mathematical problems, identify relevant information, and construct logical arguments (Pasaribu et al., 2025; Sappaile, Dhaksietsatsura, et al., 2025; Sappaile et al., 2024). Instead of exploring multiple solution strategies, they often depend on routine procedures and exhibit low flexibility in thinking. Consequently, their critical thinking skills remain underdeveloped, which negatively affects their overall mathematical performance (Atmojo et al., 2025).

The low level of students' critical thinking skills can also be attributed to limited opportunities for active learning. Traditional instructional methods rarely provide students with chances to investigate problems, collaborate with peers, or reflect on their learning processes.



Learning activities are often structured in a way that prioritizes correct answers rather than the reasoning behind them (Ismawati et al., 2023; Raisatunnisa et al., 2025). This approach reduces students' engagement and limits their ability to develop deeper conceptual understanding. In response to these challenges, there is a growing need for innovative instructional models that promote active, student-centered learning and support the development of higher-order thinking skills. One such model is Project-Based Learning (PjBL), which has gained increasing attention in recent years as an effective approach for fostering critical thinking and problem-solving skills (Chen et al., 2026; Sutamrin & Khadijah, 2021).

Project-Based Learning is a pedagogical model that engages students in learning through meaningful projects. It is characterized by student-centered activities, real-world problem contexts, collaborative work, and the production of tangible outcomes. In PjBL, students are actively involved in exploring problems, designing solutions, conducting investigations, and presenting their findings. This process encourages students to take responsibility for their learning and develop essential skills such as critical thinking, creativity, communication, and collaboration (Antika et al., 2023; Arianti Masanggelo et al., 2024).

The implementation of PjBL in mathematics learning provides opportunities for students to connect abstract concepts with real-life situations. By working on projects, students are required to analyze problems, gather and evaluate information, and apply mathematical concepts in meaningful contexts. This approach not only enhances conceptual understanding but also promotes deeper engagement and motivation. Furthermore, PjBL supports the development of critical thinking through its emphasis on inquiry and reflection. During project activities, students are encouraged to ask questions, challenge assumptions, and evaluate alternative solutions. They engage in discussions with peers, justify their reasoning, and reflect on their learning experiences. These processes align with the core components of critical thinking, including analysis, evaluation, and reasoning (Atmojo et al., 2025).

Another important aspect of PjBL is its collaborative nature. Students work in groups to solve problems and complete projects, which allows them to exchange ideas, consider different perspectives, and construct knowledge collectively. Collaborative learning environments have been shown to enhance critical thinking by encouraging dialogue, argumentation, and mutual feedback. Through interaction with peers, students develop the ability to articulate their thoughts, defend their arguments, and critically evaluate others' ideas. From a theoretical perspective, Project-Based Learning is grounded in constructivist learning theory (Analisa et al., 2026). This theory posits that knowledge is actively constructed by learners through interaction with their



environment. PjBL provides such an environment by involving students in authentic tasks that require exploration, inquiry, and reflection.

In addition, PjBL aligns with the principles of student-centered learning. In this approach, teachers act as facilitators who guide and support students rather than simply transmitting knowledge. Students are given autonomy to explore problems, make decisions, and take responsibility for their learning. This shift is essential for developing critical thinking skills. Empirical studies have demonstrated the effectiveness of Project-Based Learning in enhancing students' critical thinking skills (Maslihah et al., 2021; Toikka et al., 2024). Research findings indicate that students who participate in PjBL show significant improvement in their ability to analyze problems, evaluate information, and construct logical arguments. PjBL has also been found to increase students' motivation, engagement, and learning outcomes in mathematics.

Despite its potential, the implementation of PjBL in mathematics classrooms is still limited. Many teachers face challenges in designing and managing project-based activities, particularly in terms of time constraints, curriculum requirements, and assessment practices [REF]. As a result, traditional teaching methods remain dominant. In the context of SMP Negeri 29 Makassar, preliminary observations indicate that students' critical thinking skills in mathematics are relatively low. Students tend to rely on memorization and have difficulty analyzing problems and providing logical explanations. Learning activities are still largely teacher-centered, with limited opportunities for student interaction and exploration. Therefore, this study aims to implement the Project-Based Learning model in mathematics learning to enhance students' critical thinking skills at SMP Negeri 29 Makassar.

LITERATURE REVIEW

Project-Based Learning in Mathematics Education

Project-Based Learning (PjBL) is a student-centered instructional model that emphasizes learning through meaningful and contextualized projects (Atmojo et al., 2025; Sutamrin & Khadijah, 2021). In this approach, students actively engage in investigating real-world problems, designing solutions, and producing tangible outcomes. PjBL shifts the focus of learning from teacher-centered instruction to student-driven inquiry, where learners take responsibility for their own learning processes (Boom-Cárcamo et al., 2024; Lestari et al., 2025). In mathematics education, PjBL plays a crucial role in bridging the gap between abstract concepts and real-life applications. Mathematics is often perceived as a difficult and abstract subject, leading to low student motivation and engagement. Through project-based activities, students are given



opportunities to explore mathematical ideas in meaningful contexts, making learning more relevant and interesting. For example, students may be involved in projects that require them to apply mathematical concepts such as measurement, data analysis, or geometry in solving real-world problems.

PjBL is characterized by several key features, including problem orientation, student autonomy, collaboration, inquiry, and reflection. The learning process typically begins with a driving question or problem that guides students' investigation. Students then work collaboratively to plan and execute their projects, gather and analyze information, and present their findings. Throughout this process, teachers act as facilitators who guide and support students rather than directly providing answers. One of the major strengths of PjBL lies in its ability to promote active learning. Students are not passive recipients of information but active participants in constructing knowledge. This active engagement enhances students' understanding of mathematical concepts and encourages them to develop higher-order thinking skills. Moreover, PjBL fosters students' motivation and interest in learning, as they perceive the relevance of mathematics to real-life situations.

However, the successful implementation of PjBL requires careful planning and management. Teachers need to design meaningful projects, facilitate group collaboration, and provide appropriate guidance throughout the learning process. Challenges such as time constraints, classroom management, and assessment issues may hinder the effective implementation of PjBL. Despite these challenges, numerous studies have shown that PjBL has a positive impact on students' learning outcomes and engagement (Antika et al., 2023; Chen et al., 2026; Sutamrin & Khadijah, 2021).

Critical Thinking Skills in Mathematics Learning

Critical thinking is defined as the ability to analyze information, evaluate evidence, and make reasoned decisions based on logical reasoning. In the context of mathematics, critical thinking involves understanding problems, identifying relevant information, selecting appropriate strategies, and evaluating the validity of solutions. It is considered a higher-order thinking skill that goes beyond memorization and procedural knowledge. The development of critical thinking skills is essential in mathematics education, as it enables students to deal with complex and non-routine problems. Students with strong critical thinking abilities are able to interpret problems accurately, analyze relationships between concepts, and construct logical arguments. They are also capable of reflecting on their thinking processes and identifying errors in their reasoning (Fadli et al., 2022;



Sachdeva & Eggen, 2021).

Critical thinking in mathematics can be observed through several indicators, including problem interpretation, analysis, evaluation, inference, and explanation. These indicators align with widely recognized frameworks of critical thinking, which emphasize the importance of reasoning and reflection in the learning process. For instance, students are expected to not only solve problems but also justify their solutions and evaluate alternative approaches. Despite its importance, many students still exhibit low levels of critical thinking in mathematics. This is often due to traditional teaching methods that emphasize procedural learning rather than conceptual understanding. Students are frequently trained to follow fixed steps without understanding the underlying principles, which limits their ability to think critically (Sappaile, 2025; Sappaile, Dhaksietsatsura, et al., 2025; Sappaile et al., 2024). As a result, they struggle to solve unfamiliar problems and lack confidence in their reasoning abilities. Furthermore, the lack of opportunities for reflection and discussion in mathematics classrooms also contributes to the low development of critical thinking skills. Students are rarely encouraged to explain their reasoning, question assumptions, or evaluate their own understanding. This highlights the need for instructional approaches that actively promote critical thinking through inquiry, discussion, and reflection [REF].

The Role of Project-Based Learning in Enhancing Critical Thinking

Project-Based Learning has been widely recognized as an effective approach for developing students' critical thinking skills. The characteristics of PjBL, such as inquiry-based learning, collaboration, and reflection, provide a conducive environment for fostering higher-order thinking. Through project activities, students are engaged in complex problem-solving processes that require analysis, evaluation, and decision-making. One of the key mechanisms through which PjBL enhances critical thinking is inquiry-based learning. In PjBL, students are encouraged to ask questions, investigate problems, and seek solutions independently. This process stimulates curiosity and promotes deeper understanding, as students actively construct knowledge rather than passively receiving information (Arianti Masanggelo et al., 2024; Sappaile et al., 2024).

Collaboration is another important aspect of PjBL that contributes to the development of critical thinking. When students work in groups, they are exposed to diverse perspectives and ideas. They must communicate, negotiate, and justify their reasoning, which enhances their ability to think critically. Collaborative discussions also provide opportunities for peer feedback, allowing



students to evaluate and refine their thinking. Reflection is also a central component of PjBL. Students are encouraged to reflect on their learning experiences, evaluate their strategies, and identify areas for improvement. Reflection helps students develop metacognitive awareness, which is essential for critical thinking (Sappaile, 2025). By reflecting on their thinking processes, students become more aware of their strengths and weaknesses and are better able to regulate their learning.

Empirical studies have consistently shown that the implementation of PjBL leads to significant improvements in students' critical thinking skills. Students who participate in project-based learning demonstrate better problem-solving abilities, higher engagement, and improved academic performance (Awi & Arwadi, 2018; Michalsky, 2024). These findings suggest that PjBL is an effective instructional model for promoting meaningful learning and developing essential skills for the 21st century.

THEORETICAL FRAMEWORK

The implementation of Project-Based Learning is grounded in constructivist learning theory, which emphasizes that knowledge is actively constructed by learners through experience and interaction. According to this theory, learning occurs when students engage in meaningful activities that allow them to explore, question, and reflect on their understanding. Constructivism supports the use of PjBL as it provides opportunities for students to construct knowledge through real-world problem-solving activities. Students are not simply given information but are actively involved in discovering and applying concepts. This approach aligns with the goal of developing critical thinking skills, as students are required to analyze, evaluate, and synthesize information.

In addition, PjBL is also supported by the theory of student-centered learning, which emphasizes the active role of learners in the learning process. In this framework, teachers act as facilitators who guide students in their learning journey. Students are given autonomy to make decisions, solve problems, and reflect on their learning experiences. Furthermore, the development of critical thinking skills in PjBL can be explained through metacognitive theory. Metacognition refers to the awareness and regulation of one's own thinking processes. Through project-based activities, students are encouraged to plan, monitor, and evaluate their learning, which enhances their metacognitive skills and supports the development of critical thinking.



METHOD

Research Design

This study employed a quantitative research approach using a quasi-experimental design. This design was selected because it allows the researcher to examine the effect of an instructional intervention on students' learning outcomes without fully controlling external variables that may influence the results. In educational settings, particularly in school environments, it is often not feasible to randomly assign participants into experimental and control groups due to administrative and practical constraints.

The specific design used in this study was a one-group pretest–posttest design, in which a single group of students was observed before and after the implementation of the Project-Based Learning (PjBL) model. In this design, students were given a pretest to measure their initial level of critical thinking skills, followed by the implementation of the PjBL model during the learning process, and finally a posttest to assess the improvement in their critical thinking skills after the intervention. The structure of the research design can be illustrated as follows:

Table 1. Research Design (One-Group Pretest–Posttest Design)

Group	Pretest (O_1)	Treatment (X)	Posttest (O_2)
Experimental	Critical Thinking Test	Implementation of Project-Based Learning Model	Critical Thinking Test

This design enables the researcher to compare students' performance before and after the intervention and determine whether there is a significant improvement in their critical thinking skills.

Participants and Research Setting

The participants of this study were 32 students of SMP Negeri 29 Makassar, Indonesia. The sample was selected using a purposive sampling technique, based on the consideration that the selected class possessed characteristics relevant to the objectives of the study, including moderate academic ability and prior exposure to fundamental mathematical concepts. All participants were enrolled in a mathematics class in which the Project-Based Learning (PjBL) model was implemented. The selection of this school was grounded in preliminary observations indicating that students' critical thinking skills in mathematics were relatively low. In addition, classroom instruction was predominantly teacher-centered, with limited opportunities for



students to actively engage in problem-solving and critical thinking activities. The study was conducted in a natural classroom setting to ensure that the learning process reflected authentic educational conditions. This setting enabled the researcher to observe students' interactions, engagement, and responses during the implementation of the Project-Based Learning model in a realistic learning environment.

Research Procedure

The research procedure in this study was conducted in three main stages: preparation, implementation, and data collection. Each stage is described in detail in Table 2.

Table 2. Research Procedure

Stage	Activities
Preparation Stage	- Conducting a literature review on Project-Based Learning and critical thinking skills - Designing lesson plans based on the Project-Based Learning model - Developing research instruments, including critical thinking tests and observation sheets - Validating instruments through expert judgment to ensure validity and reliability
Implementation Stage	- Administering the pretest to measure students' initial critical thinking skills - Implementing Project-Based Learning through the following steps: 1. Problem Orientation: Introducing contextual mathematical problems 2. Project Planning: Students plan project activities collaboratively 3. Investigation: Students collect data and apply mathematical concepts 4. Project Development and Presentation: Students present their project results 5. Reflection and Evaluation: Students evaluate their learning process - Administering the posttest after the intervention
Data Collection Stage	- Collecting data from pretest and posttest results



	- Recording student activities through observation during the learning process
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Research Instruments

This study employed two main instruments to collect data: a critical thinking test and an observation sheet. These instruments were designed to measure students' critical thinking skills and their engagement during the implementation of the Project-Based Learning model.

- Critical Thinking Test

The critical thinking test was developed in the form of open-ended essay questions designed to measure students' higher-order thinking skills in mathematics. The test items were constructed based on critical thinking indicators, including interpretation, analysis, evaluation, and inference [REF].

The test consisted of several problem-solving questions related to the mathematics topic being taught. Students were required not only to provide answers but also to explain their reasoning and justify their solutions. This format allows for a deeper assessment of students' thinking processes.

The indicators of critical thinking measured in this study are presented in Table 3.

Table 3. Indicators of Critical Thinking Skills

Indicator	Description
Interpretation	Ability to understand and interpret mathematical problems
Analysis	Ability to identify relationships and relevant information
Evaluation	Ability to assess the validity of strategies and solutions
Inference	Ability to draw logical conclusions based on evidence

Before being administered, the test was validated by experts to ensure its content validity and alignment with learning objectives. In addition, the reliability of the test was examined to ensure consistency in measuring students' critical thinking skills.

- Observation Sheet

The observation sheet was used to record students' activities and engagement during the implementation of the Project-Based Learning model. It focused on students' participation, collaboration, and involvement in problem-solving activities. The observation data provided supporting information to complement the results of the critical thinking test. It also helped



the researcher understand how students interacted with the learning process and how the PjBL model influenced their behavior.

Quantitative Data Analysis

The collected data were analyzed using quantitative statistical techniques to determine the effectiveness of the Project-Based Learning model in enhancing students' critical thinking skills. The analysis procedures are as follows:

- Descriptive Statistics : Used to summarize pretest and posttest scores, including mean, minimum, maximum, and standard deviation.
- Normality Test : Conducted using the Kolmogorov–Smirnov test with a significance level of 0.05 to determine whether the data were normally distributed.
- Homogeneity Test : Performed using Levene's test to examine the homogeneity of variance between datasets.
- Paired Sample t-Test : Used to determine whether there was a significant difference between pretest and posttest scores. A significance value ($p < 0.05$) indicates a statistically significant improvement.
- N-Gain Analysis : Applied to measure the level of improvement in students' critical thinking skills after the intervention.

RESULTS

Descriptive Statistics of Students' Critical Thinking Skills

This study aimed to examine the effectiveness of the Project-Based Learning (PjBL) model in enhancing students' critical thinking skills. The data were obtained from pretest and posttest scores administered before and after the implementation of the learning model. The descriptive statistics of students' critical thinking skills are presented in Table 4.

Table 4. Descriptive Statistics of Critical Thinking Skills

Statistic	Pretest	Posttest
Minimum	48	70
Maximum	78	95
Mean	62.34	84.12
Standard Deviation	7.56	6.28



The results indicate a substantial improvement in students' critical thinking skills after the implementation of the Project-Based Learning model. The mean score increased from 62.34 in the pretest to 84.12 in the posttest. In addition, the standard deviation decreased, indicating that students' performance became more consistent after the intervention.

Normality Test

The normality test was conducted using the Kolmogorov–Smirnov test to determine whether the data were normally distributed. The results are presented in Table 5.

Table 5. Normality Test Results

	Statistic	Sig. (p)	Description
Pretest	0.129	0.200	Normal
Posttest	0.134	0.176	Normal

The results show that the significance values for both pretest and posttest scores are greater than 0.05. Therefore, the data are normally distributed and meet the assumptions for parametric statistical analysis.

Homogeneity Test

The homogeneity test was conducted using Levene's test to examine whether the variance of the data was homogeneous. The results are shown in Table 6.

Table 6. Homogeneity Test Results

Data Pair	Levene Statistic	Sig. (p)	Description
Pretest–Posttest	1.362	0.247	Homogeneous

The significance value is greater than 0.05, indicating that the variance of the data is homogeneous. Thus, the data meet the requirements for conducting a paired sample t-test.

Paired Sample t-Test

To determine whether there was a significant difference between pretest and posttest scores, a paired sample t-test was conducted. The results are presented in Table 7.



Table 7. Paired Sample t-Test Results

Data Pair	Mean Difference	t-value	Sig. (p)	Description
Pretest–Posttest	62.34 – 84.12	13.276	0.000	Significant

The results show that the significance value is $0.000 < 0.05$, indicating a statistically significant difference between pretest and posttest scores. This finding suggests that the implementation of the Project-Based Learning model has a significant effect on students' critical thinking skills.

N-Gain Analysis

The N-Gain analysis was conducted to measure the level of improvement in students' critical thinking skills after the intervention. The result of the N-Gain calculation is presented in Table 8.

Table 8. N-Gain Results

Mean Pretest	Mean Posttest	N-Gain	Category
62.34	84.12	0.58	Moderate

The N-Gain value of 0.58 indicates that the improvement in students' critical thinking skills falls into the moderate category. This result demonstrates that the Project-Based Learning model is effective in improving students' critical thinking skills.

DISCUSSION

The results of this study demonstrate that the implementation of the Project-Based Learning (PjBL) model has a significant and positive effect on students' critical thinking skills in mathematics. This finding is supported by the substantial increase in the mean score from 62.34 in the pretest to 84.12 in the posttest, as well as the statistically significant difference indicated by the paired sample t-test ($p < 0.05$). Furthermore, the N-Gain value of 0.58, which falls into the moderate category, indicates that the improvement achieved through the PjBL model is meaningful and educationally significant. The improvement in students' critical thinking skills can be explained through the characteristics of the Project-Based Learning model, which emphasizes active engagement, inquiry, and problem-solving. Unlike traditional teacher-centered approaches, PjBL provides students with opportunities to explore problems, analyze information, and construct their own understanding. This aligns with the constructivist learning theory, which



posits that knowledge is actively constructed by learners through interaction with their environment and learning experiences (Arianti Masanggelo et al., 2024; Atmojo et al., 2025).

Through the implementation of PjBL, students were actively involved in identifying problems, designing solutions, and evaluating outcomes. These processes directly correspond to the core components of critical thinking, including interpretation, analysis, evaluation, and inference. The significant increase in posttest scores suggests that students developed the ability to think more analytically and systematically when solving mathematical problems. This finding is consistent with previous studies indicating that PjBL enhances higher-order thinking skills by engaging students in meaningful and contextual learning activities (Asnani & Nasir, 2025; Sukmawati Ali, 2022). Another important factor contributing to the improvement in critical thinking skills is the collaborative nature of PjBL. During the learning process, students worked in groups to discuss problems, exchange ideas, and justify their reasoning. This collaborative interaction encourages students to consider multiple perspectives and evaluate alternative solutions. According to social constructivist theory, knowledge is constructed through social interaction and dialogue, making collaboration a key element in the development of critical thinking (Antika et al., 2023; Sutamrin & Khadijah, 2021).

Moreover, the discussion and presentation stages in PjBL play a crucial role in strengthening students' reasoning abilities. When students are required to present their findings and defend their arguments, they engage in deeper cognitive processing. This process not only improves their understanding of mathematical concepts but also enhances their ability to articulate and justify their thinking. Such activities are essential in developing critical thinking skills, as they require students to evaluate evidence and construct logical arguments (Sappaile et al., 2024). The reflection phase in the PjBL model also contributes significantly to the development of critical thinking. Reflection allows students to evaluate their learning processes, identify errors, and improve their strategies. This aligns with metacognitive theory, which emphasizes the importance of self-awareness and self-regulation in learning. Students who engage in reflective thinking are more likely to monitor their understanding and adjust their approaches when solving problems (Rahman & Jumriani, 2023; Stern & Hertel, 2022).

The moderate N-Gain value obtained in this study suggests that while the improvement is significant, there is still room for further enhancement. This may be influenced by several factors, such as the duration of the intervention, students' prior knowledge, and their familiarity with project-based learning. It is possible that longer or more intensive implementation of PjBL could lead to higher levels of improvement in critical thinking skills. In addition, the initial low level of



students' critical thinking skills, as indicated by the pretest results, highlights the need for innovative instructional approaches in mathematics education. The dominance of teacher-centered instruction limits students' opportunities to engage in higher-order thinking processes. The findings of this study confirm that shifting toward student-centered learning models such as PjBL can effectively address this issue and promote the development of critical thinking skills.

From a pedagogical perspective, this study provides important implications for mathematics teachers. The implementation of PjBL requires careful planning, including the design of meaningful projects, the facilitation of group work, and the integration of reflection activities. Teachers play a crucial role as facilitators who guide students in their learning process rather than merely delivering content. This shift in the role of teachers is essential for creating a learning environment that supports critical thinking and active learning (Fitria & Mustika, 2024; Nguyen et al., 2025). Furthermore, the findings of this study reinforce the importance of integrating cognitive, social, and metacognitive aspects in mathematics learning. Critical thinking is not only influenced by individual cognitive abilities but also by social interaction and reflective processes. Therefore, instructional models that combine these elements, such as PjBL, are more effective in developing students' higher-order thinking skills.

Overall, the results of this study provide empirical evidence that Project-Based Learning is an effective instructional model for enhancing students' critical thinking skills in mathematics. By engaging students in meaningful, collaborative, and reflective learning activities, PjBL creates a learning environment that fosters deeper understanding and promotes the development of essential 21st-century skills.

CONCLUSION

Based on the findings and discussion, it can be concluded that the implementation of the Project-Based Learning (PjBL) model is effective in enhancing students' critical thinking skills in mathematics at SMP Negeri 29 Makassar. This effectiveness is evidenced by the significant increase in students' mean scores from pretest to posttest, supported by the results of the paired sample t-test and N-Gain analysis. The application of the PjBL model provides students with meaningful learning experiences through problem-solving, collaboration, and reflection. These learning processes enable students to develop essential components of critical thinking, including interpretation, analysis, evaluation, and inference. As a result, students become more capable of understanding mathematical problems, constructing logical arguments, and evaluating their solutions. In addition to improving cognitive outcomes, the implementation of PjBL also promotes



active student participation and engagement in the learning process. Students are encouraged to take responsibility for their learning, collaborate with peers, and reflect on their thinking processes. This contributes to the development of independent and critical learners. Therefore, Project-Based Learning can be considered an effective instructional model for mathematics education, particularly in fostering critical thinking skills. It is recommended that teachers adopt and integrate PjBL into classroom practices to create more student-centered and meaningful learning environments. However, this study is limited to a one-group pretest–posttest design and a relatively small sample size. Future research is recommended to involve control groups and larger samples to obtain more comprehensive findings and to explore the long-term impact of PjBL on students' critical thinking skills.

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