

## Does Project-Based Learning Equally Foster Critical and Creative Thinking?

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### Abstract:

This research explored the effectiveness of the Project-Based Learning (PjBL) instructional model in improving critical and creative thinking skills among students at SMAK 1 Bina Bakti Bandung, Indonesia. Employing a one-group pretest-posttest quasi-experimental design, the research examined how students' critical and creative thinking skills developed after participating in a series of PjBL learning activities in polynomial topic. The findings revealed significant improvements in both critical and creative thinking skills. Critical thinking showed notably increases in all indicators (analysis, synthesis, problem solving, inference, evaluation) with the most substantial changes in synthesis and problem solving. Likewise, creative thinking also showed a remarkable improvement in all indicators (flexibility, originality, elaboration, reflection, and fluency) particularly in elaboration and fluency. The effect sizes of critical and creative thinking were measured at 0.804 and 0.949 respectively, indicating the strong impact of PjBL in improving both domains. While critical thinking exhibited comparatively elevated scores both prior to and following the intervention, the extent of enhancement was more pronounced in creative thinking. It was suggested by these results that while a relatively strong foundation in critical thinking had already been demonstrated by the students, their creative thinking skills were particularly effectively enhanced by the implementation of PjBL.

**Keywords:** critical thinking, creative thinking, project-based learning, effect size.

### Introduction

In response to the challenges of globalization and Industrial Revolution 4.0, education has a crucial role in preparing young generations to deal with rapidly evolving and diverse changes. The proficiency of 21st-century skills has become vital to help young people thrive in the complex and challenging modern world. These skills span a wide range of competencies necessary for achieving success in the context of globalization, with critical thinking and creative thinking being two of several fundamental aspects (Park et al., 2023; Ataizi & Donmez, 2014).

Critical thinking involves how students recognize and develop reasoning, use evidence, construct arguments, reach conclusions, and apply information to solve



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problems (Altun & Yildirim, 2023; Changwong et al., 2018). When students must evaluate decisions logically, critical thinking is needed (Mihail, 2022). At the same time, students also need creative thinking skills to generate and apply new ideas, find alternative explanations, and connect information to build theories or understand problems (Kurniawan & Setyaningtyas, 2025; Supriyadi et al., 2022). Creative thinking lets students see problems from multiple perspectives, which can help develop novel solutions. Critical and creative thinking skills require students to think broadly and deeply. They must use reasoning, logic, imagination, innovation, and knowledge during learning activities.

Traditional educational systems often focus on direct instruction and memorization. These approaches are less effective in developing students' critical and creative thinking skills. The focus is on one-way transfer of information—teachers are the main source, while students remain passive (Martirosov et al., 2023). As a result, students memorize facts and concepts to improve test scores, instead of gaining a deeper understanding or building analytical and creative abilities. Strict instructional models can also limit exploration and innovation, hindering students' critical and creative thinking (Firdaus et al., 2015). The lack of connection between school subjects and real-life contexts can make learning seem less relevant. Students may then be motivated only by test scores, not by a desire to understand or apply knowledge in problem-solving (Mebert et al., 2020).

To address inefficiencies in traditional education, innovation in learning is needed. This innovation should be responsive, student-centered, authentic, and collaborative. It should empower students to experiment, think critically and creatively, and find new solutions in their learning. Project-Based Learning (PBL) is promoted as an alternative model that gives students more room for exploration and innovation (Guo et al., 2020; Weng et al., 2022). PjBL lets students participate in projects linked to real-life situations, connecting lessons to broader contexts. This approach encourages critical and creative thinking for solving complex problems (Markula & Aksela, 2022; Chan, 2013). PjBL creates meaningful learning by engaging students as leaders in their process. Students analyze problems, evaluate alternatives, and develop solutions through hands-on projects (Tang et al., 2020; Alsmadi et al., 2024). Teamwork, responsibility, and improved communication are also developed as students work together.

Recent studies highlight how PjBL can boost students' engagement, motivation, and higher-order thinking skills (HOTS) by using real-world problems and collaborative environments (Zhang & Ma, 2023; Ramdani et al., 2022). Kokotsaki, Menzies, and Wiggins (2016) found that PjBL motivates students to enhance their critical and creative thinking by promoting exploration, inquiry, and self-directed understanding. PjBL lets students make meaningful connections between theory and practice, leading to deeper learning. Condliffe et al. (2017) showed that PjBL is effective for developing critical thinking. It engages students in activities requiring analysis,

evaluation, and synthesis. These processes are essential for building critical thinking by questioning assumptions, evaluating evidence, and considering alternatives. PjBL also helps creative thinking, giving students space for brainstorming, problem-solving, and conceptualization (Larson, 2011; Aisyah & Novita, 2025). Thomas (2000), Almulla (2020), and Li & Tu (2024) also found that PjBL fosters novel ideas and solutions, which are central to creative thinking.

This research examined how the PjBL model develops students' critical and creative thinking skills. The chosen research topic was polynomials. This topic involves complex algebraic operations and is often used in practical applications like predicting trends, physics, or economics (Tableh, 2020). Students often find polynomials difficult (Movshovitz-Hadar & Shmukler, 1991). The topic is challenging for its abstract nature, complex operations, and the need to understand many concepts at the same time (Osei & Agyei, 2024). Manipulating algebraic expressions, identifying degrees and coefficients, and solving polynomial equations are common challenges (Brizuela & Strachota, 2024). If not addressed using effective strategies, these difficulties can affect students' overall math performance.

To understand polynomials, students must learn basic concepts, perform operations, master factoring, handle rational expressions, and use these skills to solve equations (Bhat & Singh, 2020; Ekamornaroon et al., 2024). Mastering polynomials means students need more than procedural fluency. They also need strong conceptual understanding and advanced thinking abilities (Pelayo et al., 2023; Manandhar et al., 2022). This makes polynomials ideal for studying students' critical and creative thinking. Students must analyze relationships, evaluate solutions, and build meaningful mathematical representations. As a result, there is a need for teaching approaches that actively involve students and promote higher-order thinking.

In this context, Project-Based Learning (PjBL) is particularly relevant because it engages students with polynomial concepts through tasks that require exploration, decision-making, and solution design (Ayuningsih et al., 2022; Hamin et al., 2024). These activities encourage students to do more than just follow procedures by emphasizing authenticity and problem-solving. They also encourage students to explain their thought processes, consider different approaches to problem-solving, and generate new solutions when faced with complex and evolving situations, skills that are important for critical and creative thinking (Grant et al., 2016). By implementing the PjBL instructional model in polynomials learning, this research aims to: (1) evaluate students' critical and creative thinking skills before and after learning polynomials topics; (2) investigate the influence of PjBL on students' critical and creative thinking skills; and (3) analyze the role of PjBL in developing students' critical and creative thinking during polynomials instruction.

### Research Methods

This research employed a quantitative approach using a quasi-experimental method with a pretest-posttest one-group design. The research was conducted at

SMAK 1 Bina Bakti Bandung during the 2024/2025 academic year. The selection of this school was based on three considerations: accessibility, administrative cooperation, and compatibility with the curriculum, especially since polynomial topics are embedded within the 11th-grade mathematics syllabus. The presence of only one 11th-grade class further ensured that the data collection would be comprehensive from the entire population, without the need for sampling.

The absence of a control group restricts the capacity to draw definitive conclusions about the impact of PjBL implementation, since other factors like maturation, prior knowledge, and external learning experiences may also influence the results. Repeated exposure to similar test instruments may introduce a testing effect, affecting students' performance in the posttest. The findings should be interpreted in a certain way, particularly regarding causality (Bierer et al., 2025; Knapp, 2016).

In this research, non-test instruments in the form of questionnaires were used to collect data on students' critical and creative thinking skills. Before implementation, researchers evaluated the instruments in terms of their validity and reliability. Content validity was established through expert judgment involving three validators using a four-point relevance scale to avoid a neutral midpoint (1 = not relevant, 2 = somewhat relevant, 3 = quite relevant, 4 = highly relevant). Content validity was assessed using both the Item-Level Content Validity Index (I-CVI) and the Scale-Level Content Validity Index (S-CVI), as is typically recommended in instrument development studies (Stefana et al., 2025). The results showed that both the critical and creative thinking questionnaires had good content validity, with I-CVI values ranging from 0.667 to 1.000 and S-CVI/Ave values of 0.889 and 0.911, respectively.

After the validation process, the questionnaires were given to the students as a pretest to evaluate their starting points in terms of critical and creative thinking skills. The reliability of the instruments was then examined using Cronbach's alpha ( $\alpha$ ) coefficient based on the responses given by the students to the pretest data, which were collected prior to the implementation of the intervention. The findings indicated that the critical thinking questionnaire attained a reliability coefficient of  $\alpha = 0.842$ , signifying adequate internal consistency, while the creative thinking questionnaire yielded  $\alpha = 0.718$ , denoting acceptable reliability. These findings show that both instruments meet the minimum reliability standards required for this study.

After students completed the pretest, they participated in a series of mathematics learning sessions on polynomial topics delivered using the project-based learning (PjBL) instructional model. The classroom mathematics teacher conducted these sessions and facilitated student engagement through the structured stages of the PjBL model. At the end of the learning phase, the same questionnaires were given to the students as a posttest to see if they had improved their critical and creative thinking skills. Table 1 outlines the specific indicators and stages of the PjBL instructional model implemented in this study.

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**Table 1.** PjBL Instructional Model Used In This Research

Indicators	Teacher Activities	Student Activities
Pose Question	Guides students formulate questions that involve polynomial concepts.	Identifies questions and problems related to polynomial concepts.
Project Planning	Helps students design projects, assign tasks, and guide project activities.	Designs the project, sets goals, and distributes tasks within the group.
Research and Explore	Provides resources, facilitates discussions, and gives feedback.	Gains information and conducts research for the project.
Develop Product	Assists in the development of the final product.	Develops the final product according to the project plan.
Present and Reflect	Organizes presentations sessions and leads reflection discussion.	Presents project findings and reflects on the learning experience.

Although critical and creative thinking are typically evaluated through performance-based tasks, this study used self-report questionnaires to evaluate students' internal cognitive processes, including reasoning patterns, idea generation, and reflective thinking. These processes may not be fully observable through performance alone. Self-report instruments are commonly used to evaluate higher-order thinking skills, especially in educational settings that focus on student engagement in the learning process (Jebb et al., 2021). Additionally, using structured questionnaires ensures consistent measurement across participants and over time in a pretest–posttest design. Consequently, the utilization of Likert-scale questionnaires was considered suitable for examining alterations in students' critical and creative thinking in the scenario of PjBL implementation. Nevertheless, it is recognized that self-report instruments might not completely mirror students' real achievements, which could lead to potential bias (Fuller et al., 2018). Consideration of this limitation is essential during the interpretation of the study's findings.

The critical and creative thinking questionnaires were administered using Google Forms. This allowed for efficient data collection and accessibility for students. Each questionnaire consisted of both positively and negatively worded statements, and the responses were rated on a Likert scale (Jebb et al., 2021). This format allowed for a more nuanced assessment of the perceptions and attitudes of the students. The items in each of the questionnaires were organized according to five key indicators that were used to capture the different dimensions of critical and creative thinking. These indicators are described in detail in Tables 2 and 3.

**Table 2.** Indicators of Critical Thinking Skills

Indicators	Description
Analysis	Deconstruct information into key components to understand the structure and relationships between elements.
Synthesis	Integrate disparate ideas or information into a new, coherent, and innovative understanding.

Indicators	Description
Problem-solving	Identify core issues, evaluate solutions, and apply effective strategies to resolve issues while considering the outcomes.
Inference	Drawing reasonable conclusions based on evidence and patterns.
Evaluation	Assessing the validity, relevance, and strength of arguments or solutions based on specific criteria.

**Table 3.** Indicators of Creative Thinking Skills

Indicators	Description
Flexibility	Adapt thinking approaches and explore multiple perspectives to arrive at diverse solutions to a problem.
Originality	Produce unique, novel, and unconventional ideas that differ from traditional approaches.
Elaboration	Expand, specify, and enrich ideas to provide greater depth, structure, and applicability.
Reflection	Review one's work or ideas to identify strengths, weaknesses, and opportunities for improvement.
Fluency	Generate multiple ideas or solutions in an efficient manner in a limited amount of time.

Both descriptive and inferential statistical approaches were used to analyze the pre- and post-intervention questionnaire data. Descriptive statistics were used to summarize the central tendency and dispersion of the students' scores on the critical thinking and creative thinking questions. For the inferential statistics, preliminary tests were first carried out to make sure that the data met the necessary assumptions for further analysis. The Shapiro-Wilk test was used for the assessment of normality of the data distribution at a 5% significance level ( $\alpha = 0.05$ ). In addition, the Levene test was used to assess the homogeneity of variances between the two sets of scores. This test was also performed at  $\alpha = 0.05$ . If both conditions—normality and homogeneity—were met, the data were analyzed using the parametric paired sample t-test. This test compares the means of two related groups. If one or both assumptions were violated, the non-parametric Wilcoxon Signed Rank Test was used instead, as it does not assume a normal distribution and is suitable for ordinal or non-normally distributed interval data.

If hypothesis testing revealed a statistically significant difference between initial and final questionnaire scores, subsequent analysis determined the effect size of the PjBL model on students' critical and creative thinking skills. The effect size was calculated using Cohen's  $d$  for paired samples. Cohen's  $d$  is the mean difference between the pretest and posttest scores divided by the standard deviation of these differences (Lakens, 2013). This approach provides a standardized measure of the magnitude of change resulting from the intervention. Interpretation of Cohen's  $d$  followed the generally accepted thresholds proposed by Cohen (Lakens, 2013), where  $d \approx 0.2$  indicates a small/low effect,  $d \approx 0.5$  indicates a moderate effect, and  $d \approx 0.8$  indicates a large/high effect. To ensure clarity and consistency in reporting, all numerical results from this analysis were rounded to three decimal places.

## Results and Discussions

### Critical Thinking Skills

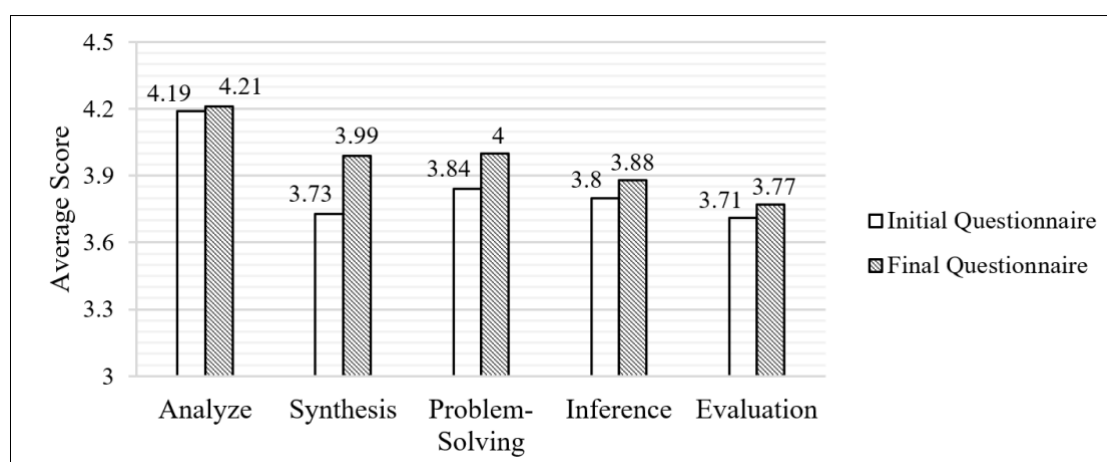
Based on the initial and final critical thinking questionnaires, this research provides data as shown in Figure 1.

Description	$\bar{x}$	$s$	Min	Max	$s^2$
Initial Questionnaire	115,955	9,204	100	131	84,712
Final Questionnaire	119,773	7,855	104	133	61,708

**Figure 1.** Students' Critical Thinking Skills Questionnaire Data.

The normality test of the initial and final critical thinking skills questionnaires gave sig(2-tailed) values of 0.198 and 0.213, respectively, both of which were greater than 0.05. This result indicated that both data were distributed normally. The homogeneity test also produced a sig(2-tailed) value of approximately 0.426, which was greater than 0.05, showing that both data sets had homogeneous variances. Following this result, for hypothesis analysis, the paired sample t-test obtained a sig(2-tailed) value of approximately 0.027, which is below the 0.05 threshold. This result rejected  $H_0$ , which confirmed that there was a significant improvement in students' critical thinking skills after the polynomial learning in the PjBL intervention. The effect size was calculated to be approximately 0.804, indicating a high effect size and confirming the effectiveness of the PjBL model in improving critical thinking skills.

Figure 2 describes further analysis of all indicators of critical thinking skills (analysis, synthesis, problem-solving, inference, and evaluation). It shows that there were improvements from the initial questionnaire to the final questionnaire based on the average score in each indicator, providing a more detailed comparison between students' baseline skills and their progress after implementing the PjBL model.



**Figure 2.** Average Score of Students' Critical Thinking Skills for Each Indicator

Significant trends in student development following the implementation of the PjBL model are evident when comparing students' initial and final questionnaire of critical thinking skills. Of the five indicators, the most notable increase was in the **synthesis** indicator, rising from 3,73 to 3,99. This substantial increase suggests that students became more adept at integrating diverse ideas and information into a new, coherent understanding. Generating solutions by combining different elements proved to be particularly effective in fostering synthesis (Yusuf et al., 2024). As a higher-order cognitive skill, synthesis benefited greatly from the hands-on, real-world problem contexts provided by the PjBL activities, which helped students make connections between their prior knowledge and new information (Wang, 2022; Boonsathirakul & Kerdsomboon, 2023).

Similarly, the **problem-solving** indicator showed an improvement, increasing from 3,84 to 4, indicating a significant development in students' ability to identify and apply effective solutions to polynomial-related problems. The hands-on, project-based nature of PjBL allowed students to actively engage in the solution of complex problems, improving their ability to solve problems (Karan & Brown, 2022; Almulla, 2020). This improvement is a reflection of how the PjBL model provided students with opportunities to apply their learning to real-world scenarios, making mathematical concepts more relevant and relatable (Rehman et al., 2024; Stoica, 2015). This active involvement is likely to have enabled the students to build more effective strategies and become more confident in their ability to handle mathematical challenges.

In addition, there was an improvement in the **inference** indicator, albeit a smaller one, from 3,8 to 3,88, which reflects the growing ability of students to draw logical conclusions based on evidence and their analysis of it. This skill is particularly important in complex subjects such as mathematics, where sound reasoning allows students to construct valid arguments and apply mathematical principles effectively (Sachdeva & Eggen, 2021). Inference is closely related to higher-order thinking skills (Darwis et al., 2024), and its improvement during the PjBL intervention suggests that students became more adept at making evidence-based decisions. This is a skill that can have broader implications beyond the classroom, such as in scientific research or professional problem solving (Kispal, 2008).

The **evaluation** indicator showed more modest gains. While students improved in their ability to evaluate the validity and relevance of solutions, progress in this area was slower than in other areas. This suggests that students may still be facing challenges when it comes to critically evaluating the strengths and weaknesses of different arguments or solutions, a skill that is crucial for higher-order thinking (Nanda et al., 2023). Several factors, including the complexity of the evaluation process, which involves not only understanding the problem at hand but also questioning underlying assumptions and considering alternative solutions, may account for this slower development in evaluation (Vincent-Lancrin, 2023).

Of all the indicators, the **analysis** indicator showed the smallest increase. This minimal improvement, however, should be interpreted in a nuanced way. First, the already high baseline score suggests that students were relatively proficient in their analytical thinking prior to the intervention. Their ability to deconstruct complex information and recognize relationships between elements may have been well developed. This may have left less room for dramatic growth. On the other hand, in spite of this apparent mastery, the limited progress may also reflect the underlying challenges of applying the skills of analysis in more complex or unfamiliar contexts. In mathematics, deep analysis requires sustained attention to detail, the ability to recognize patterns, and familiarity with a variety of strategies for solving problems (Mukuka et al., 2023). Without frequent practice and focused instruction, students may struggle to maintain or deepen these skills, especially as tasks become more cognitively demanding. Since analysis is fundamental to the development of other critical thinking skills—such as synthesis, problem solving, and evaluation—its refining is essential (Koskinen & Pitkäniemi, 2022).

The observed improvements in all of the critical thinking indicators provide compelling evidence of the effectiveness of the PjBL model in improving the higher-order cognitive skills of students in mathematics. While some measures, such as synthesis and problem solving, showed more significant growth because they are more closely aligned with the collaborative and inquiry nature of PjBL, others, such as analysis, inference, and evaluation, reflect the need for more targeted scaffolding and continued practice. These results highlight the importance of designing learning experiences that challenge students not only to find answers, but also to justify, think about, and improve their thinking process. Therefore, incorporating PjBL into the mathematics classroom can be seen as a powerful strategy for developing students' critical thinking in a comprehensive and sustainable way.

### Creative Thinking Skills

Figure 3 presents the data from the initial and final creative thinking questionnaires.

Description	$\bar{x}$	$s$	Min	Max	$s^2$
Initial Questionnaire	100,5	9,634	84	122	92,929
Final Questionnaire	106,455	9,435	92	127	89,022

Figure 3. Students' Creative Thinking Skills Questionnaire Data.

The test of normality for the initial and final creative thinking skills questionnaires yielded sig(2-tailed) values of 0.976 and 0.973, respectively. The data was considered to follow a normal distribution as both values exceeded the 0.05 threshold. In addition, the homogeneity test yielded a sig(2-tailed) value of approximately 0.857. This further confirmed that the data sets had homogeneous

variances. These statistical requirements justified the use of a paired sample t-test for the evaluation of the effect of the intervention.

The results of the paired-sample t-test revealed a sig(2-tailed) value of approximately 0.000, which was significantly below the 0.05 level. Therefore, the null hypothesis ( $H_0$ ) was rejected, indicating that there was a statistically significant improvement in students' creative thinking skills after the implementation of the PjBL model during the polynomial learning. The calculated effect size was approximately 0.949, which falls into the high effect category. This indicates that the PjBL model had a significant impact on improving students' creative thinking skills.

Figure 4 provides a comparative overview of students' performance on five indicators using data from the initial and final creative thinking skills questionnaires (flexibility, originality, elaboration, reflection, and fluency). The average scores for students' creative thinking skills showed a measurable improvement in all of the indicators after the implementation of the PjBL model during the polynomial learning. This growth suggests that the model was effective in fostering different aspects of creative thinking and in helping students not only to understand the mathematical content, but also to engage with it in more original and flexible ways.

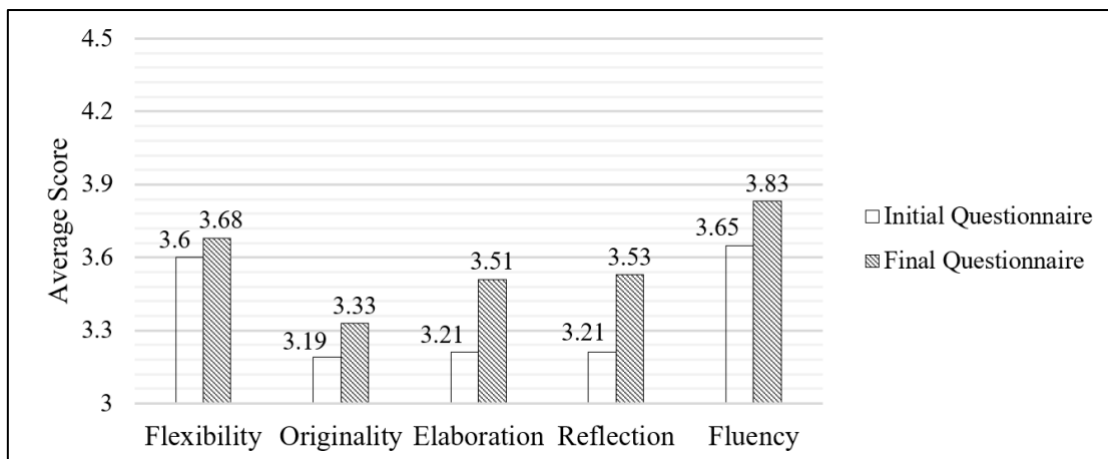


Figure 4. Average Score of Students' Creative Thinking Skills for Each Indicator

The **flexibility** indicator had the smallest increase among the five indicators. Although this improvement is modest, it suggests that students have begun to develop the ability to look at problems from a variety of perspectives and to consider alternative solutions. In mathematics, fostering flexibility means encouraging students to move away from routine methods of problem solving, especially in polynomial topics that often involve procedural manipulation (Isyrofinnisak et al., 2020; Star & Rittle-Johnson, 2008). Through PjBL, students were presented with open-ended challenges and collaborative explorations that gradually encouraged them to experiment with different pathways and connect mathematics to real-world problems (Ciffarelli & Cai, 2005). This cognitive shift may take some time to occur, but the

upward trend is promising in terms of developing students' adaptability and willingness to try out unconventional strategies.

The **originality** indicator also showed an improvement. This improvement, although still moderate, indicates that students are gaining confidence in generating novel and unique ideas. In the context of polynomial learning, originality can occur when students come up with creative representations of functions, when they invent real-world applications, or when they visualize mathematical relationships in unexpected ways (Baez et al., 2024). The PjBL model allowed students to personalize their work and contribute ideas that differed from those of their peers, moving away from the traditional "one right answer" approach that is common in mathematics classrooms (Pan & Allison, 2010). These findings suggest that originality can be fostered when students are provided with meaningful autonomy and diverse opportunities to generate ideas.

There was also a significant improvement in the **elaboration** indicator, rising from 3.21 to 3.51. Elaboration reflects the ability of students to expand on initial ideas, to add relevant details, and to structure their thoughts in a coherent manner (Vincent-Lancrin et al., 2019). This indicator is often correlated with the depth of understanding and the ability to communicate ideas effectively (Miller et al., 2018), which is a key skill in the solution of complex polynomial problems. During classroom observations, students began to organize their work in a more systematic way, detailing their steps and reasoning processes, and constructing thorough explanations of the results of their projects. This growth seems to be largely due to the fact that students were asked to document, present, or refine their solutions (Nold, 2017).

An increase was also observed in the **reflection** indicator, which improved from 3.21 to 3.53. This significant increase suggests that students have become better able to critically assess their own ideas, judge the effectiveness of their approaches, and identify areas for improvement. Reflection is a higher-order cognitive process that helps students to internalize what they have learned and to refine their strategies for moving forward in the future (Chang, 2019). Students were encouraged to revisit their thinking and align their outcomes with project goals in PjBL environments, where revision and feedback are integral to the learning cycle (Sukacké et al., 2022). As a result, students demonstrated a more mature awareness of how their ideas developed over time and how these ideas related to more general mathematical or real-world contexts (Hussein & Csikos, 2023).

Lastly, **fluency** scores increased from 3.65 to 3.83. Fluency is often the foundation upon which originality and elaboration are built, as it reflects the ability to generate a large number of ideas quickly (Handayani et al., 2021; Suherman & Vidákovich, 2022; Setianingrum et al., 2025). This increase shows that students were able to generate more ideas and solutions in response to project prompts. This may be because the PjBL model reduced the fear of failure and encouraged brainstorming without immediate judgment (Mantra et al., 2023). By providing multiple opportunities for idea

generation and peer interaction, the collaborative and iterative nature of the project work likely contributed.

The value of PjBL as an instructional model that supports multiple cognitive processes is reinforced by the observed improvements in all creative thinking indicators. These findings align with previous research emphasizing the importance of instructional strategies that promote flexibility, originality, elaboration, reflection, and fluency in developing students' ability to think creatively and critically (Biazus & Mahtari, 2022). PjBL offers a robust pathway for fostering creativity in mathematics education by integrating real-world problems, collaboration, and iterative thinking into the learning process.

To further improve students' creative thinking, especially in terms of flexibility and originality, teachers can include more open-ended and exploratory activities in the PjBL framework. Teachers can promote students' flexibility in thinking by designing activities that encourage multiple solution strategies and representations. For instance, students can solve a polynomial problem using different methods, construct polynomial functions based on conditions, or analyze incorrect solutions to identify alternative approaches. Students can model the motion of a thrown object using a polynomial function, analyze area optimization problems, or construct polynomial models based on real-world data such as sales trends. These open-ended tasks allow multiple valid approaches and solutions, thereby encouraging different strategies and representations that encourage students to develop flexibility in thought. Additionally, students can be stimulated to think in original ways when they are given tasks that require them to construct their own polynomial models based on real-world contexts. These tasks give them the freedom to generate unique ideas and approaches. Teachers may also give projects that include designing problems, changing existing models, or making different solutions. This helps students think in new ways and have new ideas for solving problems. Additionally, providing opportunities for students to present and justify different solutions can reinforce these aspects of creative thinking.

### **Critical versus Creative Thinking Skills**

A comparative analysis of students' critical and creative thinking skills throughout the implementation of the PjBL model revealed pronounced differences in the baseline levels and growth trajectories of these two cognitive domains. Specifically, students' critical thinking scores were higher at the beginning, while creative thinking showed greater improvement over time. These findings clarify that, although Project-Based Learning supports both skills, the gains differ in magnitude, providing a nuanced understanding of its impact on critical versus creative thinking.

Across the five indicators for each skill set, students consistently showed stronger performance and more significant improvement in the critical thinking domain than in the creative thinking domain. The critical thinking indicators (analysis, synthesis,

problem solving, inference, and evaluation) not only showed moderate growth but also highlighted students' ability to evaluate, organize, and validate information through logical reasoning and evidence-based judgment. These skills are very much in line with traditional academic expectations, in which structured problem solving and reasoning are emphasized as core competencies (Thornhill-Miller et al., 2023).

In contrast, creative thinking remained comparatively lower in both initial scores and subsequent growth, as measured by indicators such as flexibility, originality, elaboration, reflection, and fluency. The difference points to the more complex, nonlinear nature of creativity that requires more than the application of learned processes (Sawyer, 2021). Students are challenged to think outside the box and to develop more than one way to approach a problem. Creativity also encompasses higher levels of both ambiguity and uncertainty, as well as the courage to take cognitive risks, all of which may not be adequately fostered in traditional classroom settings (Vincent-Lancrin et al., 2019; Thornhill-Miller et al., 2023; Wechsler et al., 2025).

Creative thinking is inherently more difficult to teach, model, and assess because it often involves divergent, non-standardized outcomes (Dechaume et al., 2024). Activities that foster creative thinking require a learning environment that embraces ambiguity and prioritizes process over product, such as open-ended design projects, improvisational writing, conceptual brainstorming, or interdisciplinary synthesis (Xu et al., 2024). Such work takes longer, demands iterative feedback, and requires a pedagogical culture that values creativity equally with accuracy. Unfortunately, these conditions are not necessarily present in traditional classrooms, where time pressures, curriculum rigidity, and performance demands may limit opportunities for creative inquiry (Beghetto & Kaufman, 2014; Ji-Hoon et al., 2021).

In addition, creative thinking tends to develop in a contextual, cultural, and emotionally secure environment (Hennessey, 2015). Students need an environment that is conducive to autonomy, curiosity, and experimentation, elements that are essential for creativity to flourish. Students may become risk-averse and reluctant to share unconventional ideas in classrooms where failure is punished, or originality is not celebrated (Treffinger, 2009). Research has shown that an environment that is characterized by psychological safety, teacher encouragement, and student-centered learning is more conducive to the development of creative thinking (Qian et al., 2019; Childs et al., 2022). In this regard, more intentional scaffolding may be needed to truly unlock students' creative potential, even though PjBL provides a more conducive context than traditional instruction by emphasizing real-world relevance, collaboration, and exploration (Hafeez, 2021).

Teachers play a critical role in this process. Students' attitudes and skills related to creative thinking are shaped by their ability to design tasks that challenge students intellectually while leaving room for creativity, their willingness to accept student-generated ideas, and their ability to provide formative feedback (Tiong & Bakar, 2022).

Teachers signal to students that creativity is not only acceptable but valued when they model creative problem solving, ask open-ended questions, and validate diverse approaches. In contrast, they may inadvertently stifle creative tendencies by encouraging conformity and rote responses when instruction is overly rigid or outcome-oriented (Jia et al., 2019).

A likely explanation for this discrepancy between students' critical and creative thinking skills is the historical and systematic preference in education for critical over creative thinking (Hennessey, 2015; Beghetto & Kaufman, 2014). Standard curriculum and assessment practices have long privileged analytical skills because they can be measured and predicted (Bouckaert & Vincent-Lancrin, 2023; Robinson, 2012). For example, tasks like identifying logical fallacies, evaluating reasoning, word problem-solving, and conducting scientific analysis tend to have clear criteria for success and are easier to evaluate objectively (Berkle et al., 2023). Such tasks are prevalent in textbooks, exams, and classrooms, making critical thinking more accessible and routinely practiced by students (Davies, 2013). The need for a more balanced approach to curriculum and pedagogy is underscored by the observed gap between critical and creative thinking. While critical thinking provides tools for analysis and evaluation, creative thinking enables students to generate possibilities and envision alternatives (Vincent-Lancrin et al., 2019; Brodin, 2016). Both are essential in the context of learning in the 21st century, where complex global challenges call not only for sound judgment, but also for inventive thinking. Integrating instructional strategies that develop both cognitive domains in tandem will become increasingly important as education evolves toward more holistic and student-centered models, including approaches such as PjBL (Kulkarni & Ramdasi, 2022). Bridging the gap and cultivating learners who are both critically astute and creatively agile can be achieved by encouraging students to look at problems from multiple perspectives, iterate their ideas, and collaborate in diverse teams.

## **Conclusions and Suggestions**

The research results indicate that the Project-Based Learning (PBL) instructional model significantly improved students' critical and creative thinking skills in a polynomial topic at SMAK 1 Bina Bakti Bandung. The PjBL model, which consists of stages such as posing questions, planning projects, conducting research, developing products, and presenting findings, was found to be effective in developing students' critical and creative thinking skills. However, the results suggest that PjBL does not equally foster these two domains when addressing the main research question. While both critical and creative thinking skills improved substantially, creative thinking improved more, as reflected by the higher effect size.

Despite the improvement in both skills through PjBL instruction, there was a noticeable difference when comparing critical and creative thinking skills, as critical thinking scores were generally higher at baseline. This discrepancy can be attributed

to the students' initial performance levels. Prior to the intervention, critical thinking scores were relatively high, indicating that students already possessed a certain level of analytical ability. In contrast, creative thinking scores increased substantially, suggesting that PjBL is particularly effective in fostering creativity through open-ended and exploratory tasks.

Based on these findings, it is recommended that teachers integrate project-based learning (PBL) into their classroom instruction, particularly for projects that encourage creative thinking. Teachers should generally focus on creating authentic, real-world problems that spark curiosity and encourage exploration. This approach increases student engagement and learning outcomes. Research initiatives in the future might include using the PjBL model in different math classes and subjects to show how well it works and adapt it to different learning environments. Additionally, these initiatives may involve designing new scenarios to enhance students' creative thinking skills.

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