

Fostering critical thinking abilities through AI-integrated Problem Based Learning: A desmos-based approach

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Abstract

This research aims to describe students' critical thinking abilities on the topic of geometric transformations through the use of a Problem-Based Learning model assisted by AI Desmos. This research employed a descriptive qualitative approach. The subjects of this research were 33 students from class XI.1 of a private senior high school in Palembang. Data were collected through tests and interviews. In the analysis of test data, students' critical thinking abilities were described, while the interview data were transcribed into written form for further analysis. The results of the research indicate that students' critical thinking abilities fall into the high category, and the implementation of Problem-Based Learning assisted by AI Desmos in geometric transformation material can enhance students' critical thinking abilities. This is evident from students' ability to identify information and problems in the given tasks, formulate solution strategies, apply relevant concepts, carry out procedures, and draw conclusions.

Keywords: *Critical Thinking Abilities, Geometry Transformation, Problem Based Learning, Desmos*

Abstrak

Penelitian ini bertujuan untuk mendeskripsikan kemampuan berpikir kritis siswa materi transformasi geometri melalui model *Problem Based Learning* berbantuan AI Desmos. Jenis penelitian ini adalah penelitian deskriptif. Subjek penelitian ini adalah siswa kelas XI.1 salah satu SMA swasta di Palembang yang berjumlah 33 orang. Teknik pengumpulan datanya adalah tes dan wawancara. Pada analisis data tes, dilakukan pendeskripsian kemampuan subjek dalam berpikir kritis. Pada analisis data wawancara, dilakukan pentranskripsian hasil wawancara ke dalam bentuk tulisan. Hasil penelitian menunjukkan bahwa kemampuan berpikir kritis siswa dalam kategori tinggi dan penerapan *Problem Based Learning* berbantuan AI Desmos pada materi transformasi geometri dapat meningkatkan kemampuan berpikir kritis siswa. Hal ini terlihat dari siswa yang mampu mengidentifikasi informasi dan permasalahan pada soal, merumuskan strategi penyelesaian, menerapkan suatu konsep, melakukan prosedur dan menarik kesimpulan.

Kata kunci: Kemampuan Berpikir Kritis, Transformasi Geometri, Problem Based Learning, Desmos

INTRODUCTION

Critical thinking is one of the essential skills students need to compete in the future (Samadun & Dwikoranto, 2022). According to Ziatdinov & Valles (2022), *critical thinking* refers to the process of thinking deeply and using reasoning to acquire accurate and accountable knowledge. Critical thinking enables students to seek the truth and select appropriate information for use in everyday life (Cahyani et al., 2021). Mathematics and critical thinking are closely interconnected, as mathematical concepts can be understood through critical thinking abilities, and critical thinking can be fostered through the processes involved in learning mathematics (Hafiz et al., 2020.)

However, in practice, students' critical thinking abilities remain low. The research by Simanullang et al., (2023) showed that 6,06% of students demonstrated very low critical thinking abilities, 57,58% exhibited low critical thinking abilities, and 36,36% possessed moderate critical thinking abilities. No students were identified as having high or very high levels of critical thinking. Students' critical thinking abilities in geometry transformation topics are also notably low (Rahmawati et al., 2021; Taihuttu et al., 2021), including among students in a private senior high school in Palembang. This issue was confirmed through interviews with teachers from the school, who reported that students struggle to understand geometry transformation concepts, particularly in the subtopics of reflection and rotation. Students find it difficult to solve problems involving reflection and rotation because they lack an understanding of the underlying concepts. Reflection formulas vary depending on the line of reflection, while rotation involves trigonometry, requiring students to memorize numerous sine and cosine values. This finding aligns with the results of Wasilah et al. (2023), who reported that students face difficulties in solving reflection and rotation problems due to a lack of conceptual understanding and forgetting the corresponding formulas.

The low level of students' critical thinking abilities is attributed to the fact that classroom instruction is still predominantly teacher-centered, which limits opportunities for active learning that could optimize students' thinking potential (Rahman et al., 2022; Salim & Disman, 2023; Tanujaya et al., 2021). Similarly, Setyawati et al. (2022) argue that the lack of critical thinking abilities arises from the absence of instructional models specifically designed to enhance critical thinking, resulting in students' difficulties in solving mathematical problems. Another contributing factor is the limited ability of teachers to visualize mathematical concepts effectively (Ziatdinov & Valles, 2022) and the infrequent use of instructional media, including AI-based media (Susanti et al., 2023). Even when instructional media are used, they often fail to improve students' critical

thinking abilities, including in geometry transformation topics (Rahmawati et al., 2021; Taihuttu et al., 2021.)

One instructional model that can be employed to foster and enhance students' skills, particularly critical thinking and problem-solving, is the Problem-Based Learning (PBL) model (Fang et al., 2023; Samadun & Dwikoranto, 2022). According to Susanto (2020), Problem-Based Learning is a pedagogical approach centered on solving real-world problems, engaging students in group activities, feedback sessions, and discussions that promote exploration and the creation of final reports. This method encourages greater student engagement with learning materials and fosters the development of critical thinking abilities. PBL actively involves students in solving problems through various stages of the scientific method, enabling them to acquire knowledge relevant to the problems at hand while simultaneously enhancing their problem-solving abilities.

One AI-based tool that can effectively visualize geometry transformations is the Desmos Geometry Tool, which is highly compatible with the Problem-Based Learning model. One key characteristic of PBL is that students engage in authentic investigations, with the inquiry methods tailored to the nature of the problems they face Arends (2012). Desmos facilitates students in conducting authentic mathematical activities (Kristanto, 2021), making it an ideal tool for such investigations. These mathematical activities can be designed and organized through the Desmos Classroom Activities feature available in Desmos Classroom.

Previous studies by Nurfajri et al. (2023) and Rahmatika, (2022) have explored students' critical thinking abilities using Wizer.Me as an electronic worksheet (E-LKPD) and Geogebra as instructional media, respectively. Desmos offers several advantages over these two media. Unlike Wizer.Me, Desmos Classroom Activities are structured similarly to an E-LKPD, allowing students to conduct investigations and explorations within Desmos itself without opening additional tabs, while their work is automatically saved within the platform. Furthermore, teachers can monitor every student's progress in real time through their teacher accounts. Compared to Geogebra and its classroom activities, Desmos Geometry Tool is more user-friendly and offers more comprehensive features within Desmos Classroom Activities.

Based on the aforementioned considerations, this research will be conducted under the title: "Fostering Critical Thinking Abilities Through AI-Integrated Problem-Based Learning: A Desmos-Based Approach." The aim of this research is to describe students' critical thinking abilities on geometry transformation topics through the implementation of the Problem-Based Learning model supported by Desmos.

RESEARCH METHODS

This research employs a descriptive research design, focusing on students' critical thinking abilities in geometry transformation topics through the implementation of the Problem-Based Learning (PBL) model supported by Desmos. The research subjects comprised 33 eleventh-grade students from class XI.1. The research was conducted during the first semester of the 2024/2025 academic year at a private senior high school in Palembang.

Two primary instruments were used for data collection: tests and interviews. The test instrument was designed to measure students' critical thinking abilities after receiving instruction through the PBL model supported by Desmos, while interviews were conducted to gain deeper insights into the students' critical thinking processes when answering the test questions. Prior to their use, both instruments were validated by experts using an expert judgment technique. The validation process aimed to ensure that each instrument was appropriate, relevant, and capable of accurately measuring the intended constructs. The validation results were used to revise and refine the instrument items to align with the research context and objectives.

Data analysis in this research utilized a descriptive quantitative approach. The data analyzed were derived from written test results aimed at measuring and describing students' levels of critical thinking based on indicators such as providing simple explanations, organizing strategies and tactics, developing basic skills, offering further explanations, and drawing conclusions. The test results were then categorized according to the classification guidelines of students' critical thinking abilities as developed by Ayudia & Mariani, (2022). Although this research primarily focused on quantitative data, interviews were employed as supporting data to provide additional context to the test results. The interview data were not analyzed through in-depth qualitative methods but were used to strengthen the interpretation of the quantitative findings.

Table 1. Categories of students' critical thinking abilities

Students' Critical Thinking Abilities Score Interval	Category
80 - 100	Very High
66 - 79	High
56 - 65	Medium
40 - 55	Low
≤ 39	Very Low

RESULTS AND DISCUSSION

The learning activities were designed in accordance with the Problem-Based Learning (PBL) model supported by Desmos and were conducted over two sessions. The main topic of the first session focused on reflections. In the problem orientation stage, the researcher explained the context of the problem and asked students to identify the known information and the questions being posed, aiming to develop the indicator of providing simple explanations. In the student organization stage, students were divided into seven heterogeneous groups, each consisting of five members. No significant obstacles were encountered during these two stages. In the stage of guiding individual and group investigations, students began working on the Desmos Classroom Activity, which could be accessed via the following link: <https://teacher.desmos.com/activitybuilder/custom/66b84a70bcf5fd390e182aa>. Several displays from the activity are presented below.

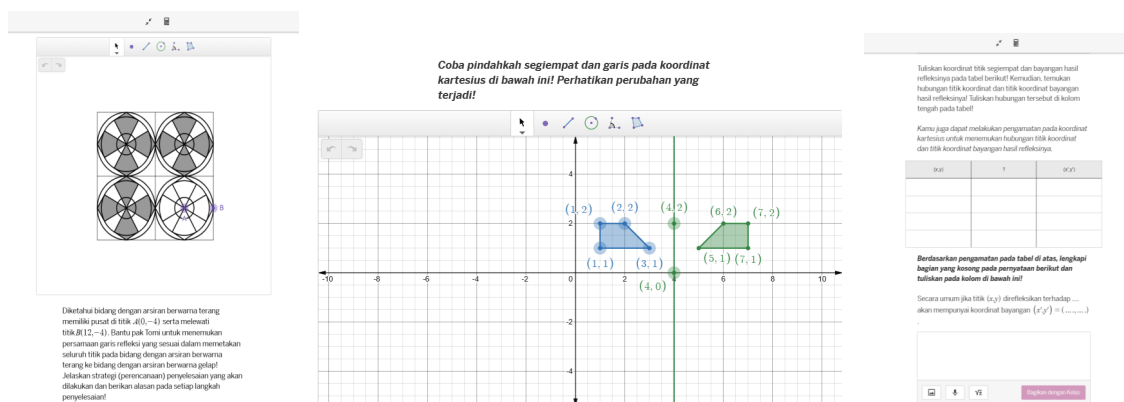


Figure 1. Display of Desmos Classroom Activity in the first session

During the lesson, the researcher monitored and guided students as they engaged with the Desmos Classroom Activity and tracked their progress through the teacher's Desmos Classroom account. The first session activity consisted of nine slides covering the learning objectives and group member identities, an introduction, problem orientation, exploration of reflections using Desmos, the definition and properties of reflections, reflection formulas, transformation matrix equations, and problem-solving tasks designed to integrate the five indicators of critical thinking abilities.

In the exploration stage, students manipulated geometric shapes by altering the shape of quadrilaterals, repositioning the figures, changing the slope of the line, and moving the line itself to deepen their understanding of reflections. For instance, Group 1

transformed a right trapezoid into a square, while Group 2 adjusted the line's slope so that the line represented the equation $y = x$. Subsequently, students defined reflections and identified their properties to develop the “drawing conclusions” indicator. They also analyzed coordinate patterns to discover the reflection formulas, fostering the “organizing strategies and tactics” indicator, and then derived the transformation matrix equations by applying algebraic operations to enhance the “building basic skills” and “providing further explanation” indicators.

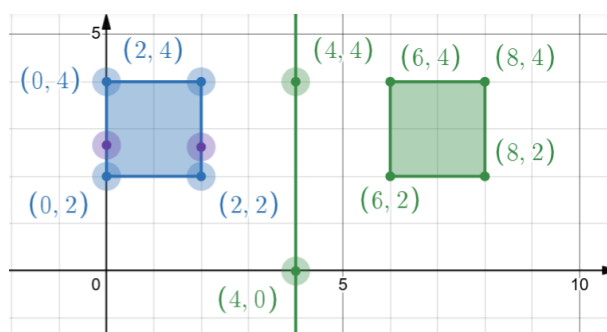


Figure 2. Desmos Display of Group 1's Exploration Results

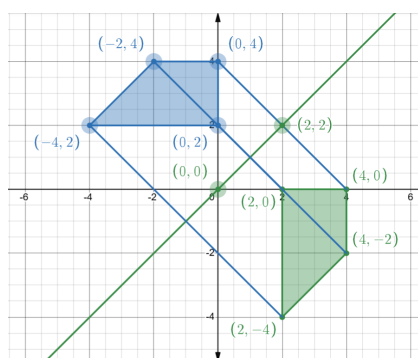


Figure 3. Desmos Display of Group 2's Exploration Results

The challenges encountered during the individual and group investigation phase included time constraints that limited intensive guidance, students' insufficient understanding of prerequisite materials, limited availability of laptops which forced some students to use smartphones with small screens, and unstable internet connections that slowed down the process.

In the phase of developing and presenting the final product, all groups successfully submitted their Desmos Classroom Activities, and group representatives presented their discussion results in front of the class. No significant obstacles were encountered during

this stage. In the phase of analyzing and evaluating the problem-solving process, a question-and-answer session was conducted; however, time limitations restricted the number of responses that could be analyzed and discussed. Subsequently, the researcher provided evaluation and reinforcement.

The learning activities in the second session followed the same structure as the first session but focused on the topic of rotation. The Desmos Classroom Activity for the second session could be accessed via the link: <https://teacher.desmos.com/activitybuilder/custom/66b8474efc06c2a93c9b963>.

Critical Thinking abilities Test Results

In the third session, a critical thinking abilities test was administered, followed by interviews in the fourth session with five selected participants representing the categories of very high, high, medium, low, and very low levels of critical thinking. The results of the critical thinking abilities test are presented below.

Table 2. Average Critical Thinking Abilities Score

Interval	Frequency	Percentage	Category
80 - 100	2	6,06%	Very High
66 - 79	14	42,42%	High
56 - 65	5	15,15%	Medium
40 - 55	4	12,12%	Low
≤ 39	8	24,25%	Very Low
Sum		33	
Category		High	

Very High-Level Critical Thinking Ability (MAA)

Based on the analysis of the answers and interview results, MAA demonstrated mastery of all five indicators of critical thinking ability in both questions provided. However, several minor mistakes were identified, primarily due to lapses in concentration. MAA's answers to questions 1 and 2 are presented below.

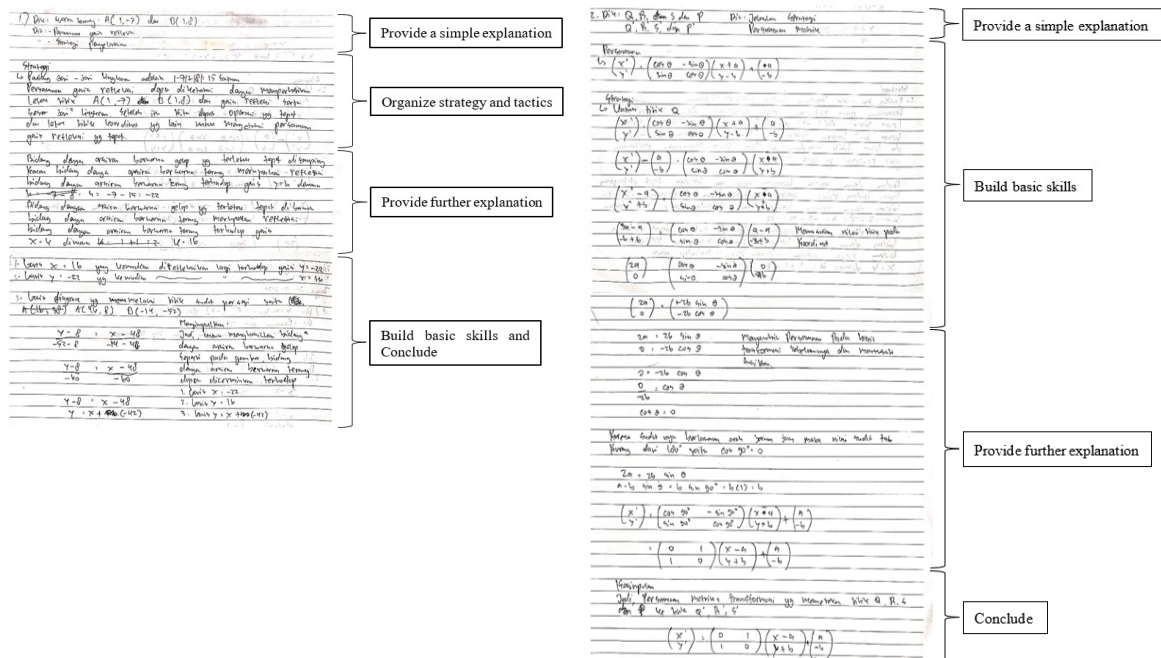


Figure 4. MAA's answer sheet

MAA was able to provide a clear and concise explanation by accurately stating the known information and the questions being asked. Regarding the indicator of strategy and tactics organization, MAA outlined a strategy for the first question but omitted it for the second question out of concern for time constraints. For the basic skills building indicator, MAA successfully determined the coordinates of a point on the diagonal reflection line and applied algebraic operations to find the reflection line equation. However, MAA made an error by substituting the point (48,8) as, (46,8) leading to an inaccurate conclusion. MAA also accurately substituted a point into the rotational transformation matrix equation and performed matrix operations correctly. In terms of providing further explanation, MAA was able to apply the concepts of circle radius and reflection to derive the equations for horizontal and vertical reflection lines, as well as use the equality of two matrices to correctly determine the rotation angle. Nonetheless, a substitution error involving the value of $-\sin\theta$ led to an inaccurate conclusion.

Medium-Level Critical Thinking Ability (RL)

Based on the analysis of the answers and interview results, RL demonstrated mastery of all five indicators of critical thinking ability in both questions. However, RL made mistakes in the basic skills building indicator on question 1 and in providing further explanation on question 2. RL's answers to questions 1 and 2 are presented below.

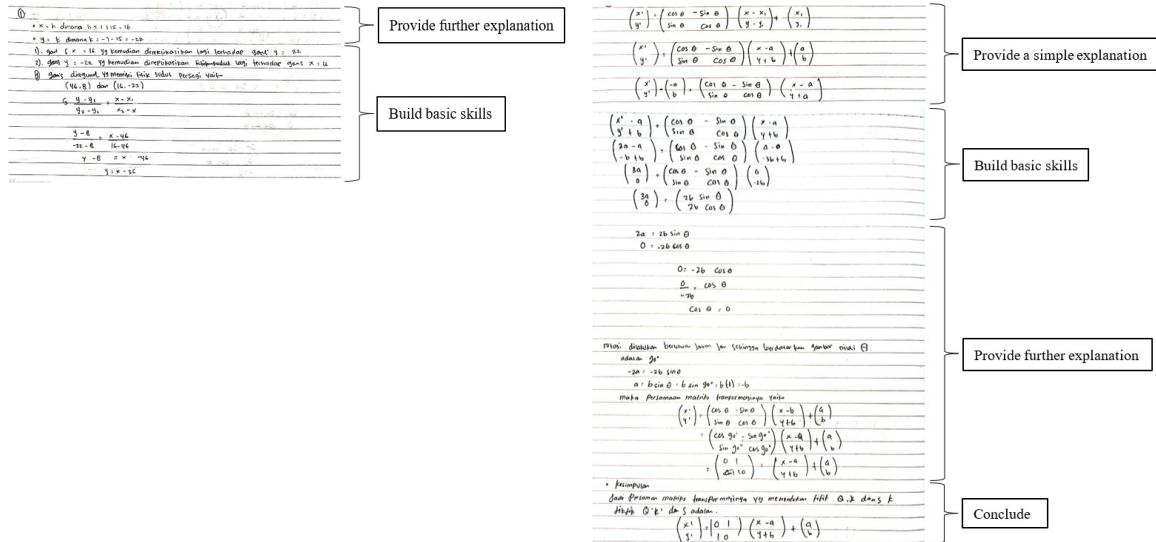


Figure 5. RL's answer sheet

RL was able to provide a clear explanation by using the given information to solve the problem and correctly wrote the formulas. For the strategy and tactics indicator, RL did not write down the problem-solving strategy but was able to explain it during the interview. RL admitted difficulty in expressing the strategy in words and was concerned about running out of time to complete the questions. Regarding basic skills building, RL was able to determine the coordinates on the diagonal reflection line but was unable to carry out the necessary algebraic operations, leading to an inaccurate conclusion. RL correctly substituted points into the rotational transformation matrix equation and performed the matrix operations accurately. For providing further explanation, RL successfully applied the concepts of circle radius and reflection to derive the equations for horizontal and vertical reflection lines, as well as used the equality of two matrices to determine the rotation angle. However, an error in substituting the value of θ resulted in incorrect coordinates for point P, and an additional substitution error with the value of $-\sin\theta$ led to an inaccurate conclusion.

Low-Level Critical Thinking Ability (FSL)

Based on the analysis of the answers and interview results, FSL demonstrated mastery of only the simple explanation indicator in both questions and partially mastered the strategy and tactics indicator in the second question. FSL's answers to questions 1 and 2 are presented below.

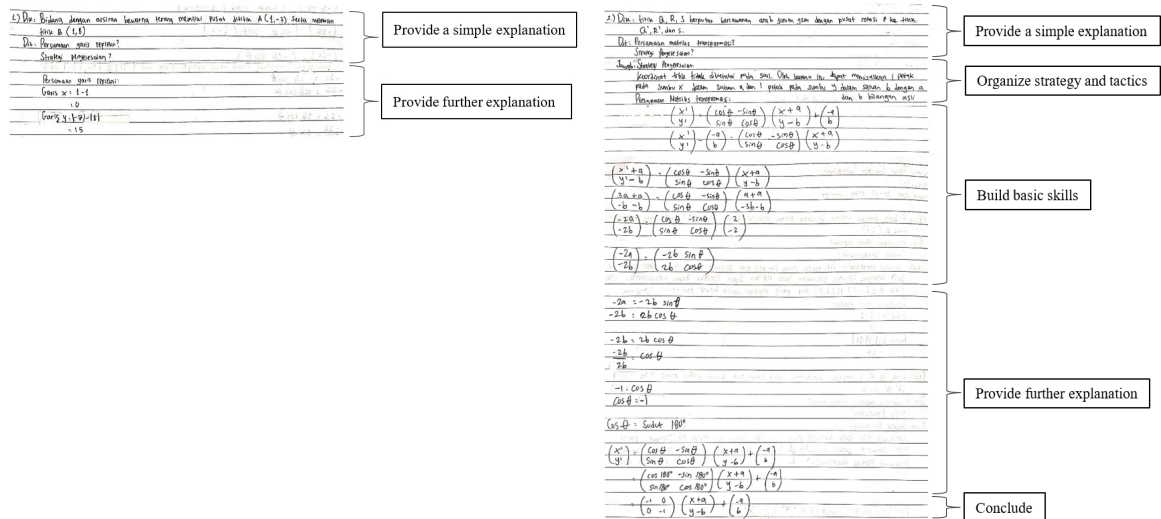


Figure 6. FSL's answer sheet

FSL was able to provide a clear explanation by accurately stating the known information and questions. Regarding the strategy and tactics indicator, FSL was only able to formulate a strategy for solving the rotation problem but failed to formulate a strategy for solving the reflection problem. In terms of basic skills building, FSL was unable to determine the coordinates on the diagonal reflection line, identify the center of rotation, or perform the necessary algebraic and matrix operations. Consequently, for the indicator of providing further explanation, when applying the concept of two equal matrices, FSL derived two incorrect equations, leading to an inaccurate conclusion. FSL was also unable to apply the concepts of circle radius and reflection to find the equations of the horizontal and vertical reflection lines due to the inability to formulate an appropriate problem-solving strategy. The following is an excerpt from the interview transcript with FSL:

Researcher: What problem-solving strategy did you use to solve the reflection problem?

FSL : I tried to find the equation of the reflection line by subtracting the coordinates of points A and B, ma'am.

Researcher: So, $x = 1-1$ and the line $y = |-7|-|8|$ were both derived from the coordinates of points A and B, right? Why does the x-equation have no absolute value sign while the y-equation does?

FSL : So the resulting line wouldn't be negative, ma'am. Because if we look at the figure, it seems like none of the lines have negative values.

The results of this research indicate that the implementation of the Desmos-assisted Problem-Based Learning (PBL) model has made a positive contribution to the development of students' critical thinking abilities in mathematics learning, particularly

on the topic of geometric transformations, specifically reflections and rotations. Over two learning sessions, students were engaged in problem-based learning activities utilizing the Activity Builder feature on the Desmos platform to visually, interactively, and systematically explore the concepts of reflection and rotation. A total of 48.48% of students were classified into high and very high categories, indicating that most students successfully enhanced their critical thinking abilities. The use of Desmos provided students with the opportunity to manipulate geometric objects and understand relationships between elements dynamically, which aligns with the characteristics of problem-based learning. These activities also encouraged students to analyze data, formulate hypotheses, and develop generalizations based on their visual explorations.

Students in the very high category, such as MAA, demonstrated mastery of all five critical thinking indicators, as evidenced by their ability to comprehend problem information, formulate solution strategies, apply concepts such as the radius of a circle and the equality of two matrices, perform procedures such as algebraic operations and matrix operations, and draw conclusions. However, minor errors in point substitution and trigonometric values in matrices were observed due to lapses in focus. Meanwhile, RL, who was categorized at the moderate level, was able to correctly write formulas and utilize information, as well as apply concepts, but struggled to articulate solution strategies verbally and was less accurate in performing algebraic operations and substitutions. FSL, representing the low level of ability, encountered difficulties in formulating strategies, applying concepts, and accurately completing algebraic and matrix calculations. These findings suggest that students' critical thinking abilities are closely linked to their mastery of prerequisite material and their ability to communicate solution strategies in written form.

Although the Desmos-assisted PBL model showed considerable potential in enhancing students' critical thinking abilities, this research also faced several limitations. First, time constraints during the learning process limited the effectiveness of discussions and the teacher's ability to provide comprehensive guidance to each group. Second, not all students brought suitable devices to access Desmos comfortably, requiring some to use mobile phones with small screens that hindered exploration. Third, internet connectivity issues posed technical challenges that slowed down the learning process. Additionally, the lack of mastery of prerequisite material, such as matrix operations and basic algebra, presented further challenges for some students. Several students also struggled to express solution strategies in written form due to limited verbal or mathematical literacy. This finding aligns with Hayati & Setiawan (2022), who stated

that language limitations can hinder students' critical thinking abilities. Methodologically, the limitation of this research lies in its descriptive design, which does not allow for direct quantitative measurement of critical thinking improvement or comparison of the effectiveness of Desmos-assisted PBL with other instructional models. Furthermore, the sample was limited to one class from a single school, preventing broad generalization of the findings. The validity of the data also relied heavily on the researcher's interpretation of test and interview results, which may contain subjective bias.

Based on the findings and the constraints encountered, several recommendations are proposed for future research and instructional development. First, it is essential to strengthen students' prerequisite knowledge before commencing core instruction, particularly in algebraic operations and matrix transformations, to better prepare students for problem-based tasks (Alifa et al., 2024; Maulida et al., 2022). Second, mathematical literacy exercises should be incorporated into lessons to help students practice systematically articulating ideas and solution strategies. Third, the use of digital tools such as Desmos in learning should be supported by adequate infrastructure, including the availability of laptops and stable internet connections. Fourth, instructional time should be extended or structured as take-home assignments to allow for more thorough exploration and discussion. Finally, to quantitatively assess the model's effectiveness, future research could adopt a quasi-experimental approach with larger control and experimental groups.

Overall, the integration of PBL with digital technology such as Desmos has been shown to foster a challenging and meaningful learning environment for students. This model encourages active student engagement in the critical thinking process, particularly in analyzing patterns, formulating generalizations, and solving contextual problems (Adhelacahya et al., 2023; Permata et al., 2022). Desmos offers an interactive and visual learning experience, which facilitates deeper understanding of mathematical concepts (Chechan et al., 2023; Chorney, 2022). Therefore, this approach can serve as an effective alternative for enhancing students' critical thinking abilities, especially in mathematics instruction that demands conceptual understanding and higher-order thinking abilities.

CONCLUSION

This research demonstrates that the application of the Desmos-assisted Problem-Based Learning model effectively enhances students' critical thinking abilities on the topic of geometric transformations, specifically reflections and rotations. Nearly half of the students achieved high or very high levels, indicating significant progress in critical

thinking abilities. High-achieving students were able to identify information and problems within the questions, formulate solution strategies, apply relevant concepts, carry out procedures, and draw conclusions. Conversely, low-achieving students faced challenges in mastering prerequisite material, formulating solution strategies, and applying concepts. The limitations of this research include time constraints, inadequate access to digital devices, internet connectivity issues, and a descriptive research design that restricts generalizability and causal inference. Overall, Desmos-assisted PBL successfully created an engaging and effective learning environment for fostering critical thinking in mathematics. Future research is recommended to employ experimental designs with larger sample sizes and improved infrastructure to validate these findings.

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