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STUDENTS' MATHEMATICAL CRITICAL THINKING SKILLS AND DIFFICULTIES IN SOLVING GEOMETRY PROBLEMS: AN ANALYSIS

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ABSTRACT

Critical thinking is widely recognized as a key competence in mathematics education; however, many students still struggle to apply it when solving problems. This suggests that the role of critical thinking in mathematics learning needs to be examined more closely. This study describes the overall level of students' mathematical critical thinking skills and investigates the challenges they experience in utilizing these skills during the process of solving geometry problems. A mixed-methods research design was employed involving 76 junior high school students aged 13–14 years. The quantitative phase utilized a paper-and-pencil test to provide an overview of students' mathematical critical thinking levels, while the qualitative phase explored the specific difficulties students encountered in applying these skills during problem solving. The findings indicate that students' mathematical critical thinking skills were at a moderate level, with an overall mean score of 65.62. Of the 76 students involved in the study, 13 students (17.1%) were classified in the low category, 50 students (65.8%) were in the medium category, and 13 students (17.1%) were categorized at the high level. The main difficulties identified were related to reasoning coherence, unit representation, and conclusion formulation. The results of this study are expected to provide valuable insights for mathematics teachers in designing more effective instructional strategies to foster students' critical thinking in geometry learning.

Keywords: Mathematics Education, Geometry, Problem Solving, Mathematical Critical Thinking

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INTRODUCTION

The Indonesian curriculum emphasizes the development of students' critical thinking skills as a fundamental competency to be nurtured from kindergarten through senior high school. This focus is consistent with global perspectives that consider critical thinking as an essential twenty-first century competence (Romero-Ariza, Quesada-Armenteros, & Estepa-Castro, 2024). Critical thinking is a rational and reflective mental process used to determine what to believe or how to act. It refers to a cognitive process that examines various alternatives in order to reach a rational decision, and it is acknowledged as an essential requirement for becoming a responsible member of society (Syaiful, Huda, Mukminin, & Kamid, 2022).

Furthermore, critical thinking is recognized as an essential component of education. Critical thinking is regarded not as a subject-specific skill but as a general ability that should be integrated across all disciplines, including mathematics. In mathematics learning, critical-thinking skills are a vital component that cannot be separated from students' ability to analyze problems, and therefore should be integrated into the learning process. Consequently, students are expected to construct their own understanding and knowledge in order to articulate and communicate their ideas when solving problems (Syafril et al., 2020).

Although critical thinking is widely recognized as an essential skill in mathematics problem-solving, many students still struggle to demonstrate adequate levels of critical thinking when solving mathematical problems. Critical thinking is closely connected to the goals of both national and international assessments. The Indonesian Minimum Competency Assessment (AKM) emphasizes reasoning and problem-solving in real-life contexts, reflecting its central role in the curriculum (Wijaya & Dewayani, 2021). Similarly, PISA, which focuses on applying knowledge to unfamiliar situations, also requires students to demonstrate higher-order thinking such as analysis and evaluation (OECD, 2023), where Indonesian students often face challenges. Despite these expectations, the data indicate that Indonesian students continue to perform poorly in both national (AKM) and international (PISA) assessments, particularly on tasks requiring reasoning and justification (OECD, 2023). Indonesian students' performance in AKM has shown little improvement between 2021 to 2024 (Kemendikbud, 2022, 2023, 2024). The lack of critical thinking skills appears to be one of the key factors behind these persistent difficulties, suggesting that the role of critical thinking in mathematics learning needs to be more closely considered.

Geometry, as a core strand of the mathematics curriculum, is one of the areas where students frequently encounter difficulties in applying critical thinking (e.g., Anastia, Nurcahyono, & Setiani, 2024). The persistent struggles observed in geometry highlight the urgent need to investigate how students demonstrate or fail to demonstrate critical thinking within this area. This study contributes to the existing body of research by providing deeper insights into students' critical thinking skills in mathematics, particularly in the context of geometry. This research examines more closely which specific indicators of critical thinking are strong and which are still weak among students. By identifying these patterns, the findings can serve as a valuable reference for mathematics teachers in designing more effective instructional strategies.

Previous studies on mathematical critical thinking have predominantly focused on examining its development through specific instructional approaches, such as problem-based learning, project-based learning, and STEM-oriented instruction, which have been shown to positively influence students' critical thinking skills (Rahmawati, Juandi, & Nurlaelah, 2022). Other research has emphasized the importance of mathematical critical thinking in learning mathematics (Rahmaini & Chandra, 2024) or has analyzed students' critical thinking abilities in relation to certain variables, such as learning styles or adversity quotient (Mei, Sa'o, & Naja, 2021). Meanwhile, studies on geometry learning difficulties have reported that students commonly struggle with understanding geometric concepts, transforming problems into mathematical models, applying appropriate solution procedures, and formulating conclusions, largely due to the abstract and complex nature of geometry (Nu'man & Azka, 2023). However, despite these contributions, limited attention has been given to a detailed analysis of students' mathematical critical thinking dimensions in geometry tasks using a specific critical thinking framework. In particular, there is a lack of studies that systematically map students' levels of mathematical critical thinking and identify their difficulties based on established indicators of critical thinking. Therefore, this study addresses this gap by mapping students' levels of mathematical critical thinking and identifying their difficulties using the Critical Thinking Framework proposed by Monteleone, Miller, & Warren (2023), while also

offering pedagogical implications for classroom practice to support the development of students' mathematical critical thinking skills in geometry.
Accordingly, the study addressed the following research questions; (1) What is the overall level of students' mathematical critical thinking skills? (2) What difficulties do students encounter when applying mathematical critical thinking in solving geometry problems?

METHOD

Research Design

This study employed a mixed-methods research design. A mixed methods research design refers to an approach that combines the collection, analysis, and integration of both quantitative and qualitative data within a single study or across a set of studies in order to gain a more comprehensive understanding of a research problem (Creswell, 2012). Specifically, this study adopted an explanatory sequential design, beginning with a quantitative phase followed by a qualitative phase that was used to elaborate on the quantitative results.

The quantitative phase involved a paper-and-pencil test administered to all participants in order to capture a broad picture of their mathematical critical thinking skills. Based on the results, six students were purposively selected to represent different levels of ability low, medium, and high in critical thinking. This selection follows the suggestion of Miles, Huberman, & Saldaña (2014) that case selection in qualitative research should capture variation across key dimensions while still allowing an in-depth exploration of each case. The main emphasis of the qualitative phase was on exploring the difficulties that students encounter when applying mathematical critical thinking in solving geometry problems

Participants

The participants of this study were 76 junior high school students (Grade 8, aged 13–14 years) from public junior high schools in Mataram, West Nusa Tenggara. The students were selected using convenience sampling, as the schools and classes were accessible to the researcher. All students from the selected classes participated in the quantitative phase of the study.

Instruments

The main instrument used in the quantitative phase was a Mathematical Critical Thinking Test. The test consisted of five open-ended geometry problems focusing on volume adn syrface of flat-sided ssolid shapes. Each item was designed to assess students' abilities in interpreting, analyzing, and evaluating mathematical information based on the Critical Thinking Framework proposed by Monteleone et al. (2023).

Data Analysis

The quantitative data obtained from the test were analyzed using descriptive statistics, including minimum, maximum, mean, and standard deviation, to determine the overall level of students' mathematical critical thinking. Students' test scores were further categorized into low, medium, and high levels. To categorize students' levels of mathematical critical thinking, this study employed the mean and standard deviation approach (see table 1), which is commonly used in educational and psychological research to classify scores into high, medium, and low categories (Azwar, 2012).

Table 1. Students' Level Category

Categorize	Score
High	$X \geq 77$
Medium	$55 \leq X < 77$
Low	$X \leq 77$

For the qualitative phase, six students' written responses to geometry problems were examined using content analysis . The analysis was guided by the Critical Thinking Framework (see Table 2), adopted from the initial framework of critical mathematical thinking proposed by Monteleone et al. (2023) which builds on the foundational works of Facione (1990) and Ennis (1989), The qualitative analysis was conducted through several stages. First, open coding was performed by carefully reading students' written responses to identify meaningful units related to critical thinking processes. Second, the identified codes were categorized according to the framework indicators, namely interpreting, analyzing, and evaluating. Finally, the categorized data were interpreted to identify patterns of students' strengths and difficulties in applying mathematical critical thinking when solving geometry problems. This framework served as the conceptual lens for coding and interpreting students' solutions.

Table 2. Critical Thinking Framework

Mathematical Critical thinking themes	Sub themes
Interpreting	Assessing Assuming Clarifying Categorising Decoding Examining Identifying
Analysing	Applying Conjecturing Drawing conclusions Hypothesising Inferring Querying
Evaluating	Assessing claims and arguments Judging Querying evidence

RESULT

Research Question 1: What is the overall level of students' mathematical critical thinking skills?

Table 3 shows the descriptive statistics score on the mathematical critical thinking test among the 76 students involved in the study.

Table 3. Descriptive Statistics of Students' Scores on the Mathematical Critical Thinking Test

Description	Value
N	76
Minimum Score	39
Maximum Score	89
Mean	65.62
Standard Deviation	11.43

Table 3 above summarizes the descriptive statistics of students' scores on the mathematical critical thinking test. The results show that the lowest score achieved by students was 39, while the highest score reached 89. The overall mean score was 65.62 with a standard deviation of 11.43. These findings suggest that students demonstrated a moderate level of critical thinking ability, indicating that many students are still not yet reached a consistently high level of performance.

Table 4 shows a detailed of the distribution of students across different levels of mathematical critical thinking.

Table 4. Distribution of Students Across Different Levels of Mathematical Critical Thinking

Description	Frequency	Percent
Low	13	17.1%
Medium	50	65.8%
High	13	17.1%
Total	76	100%

Table 4 provides a more detailed of the distribution of students across different levels of mathematical critical thinking. Of the 76 students, 13 (17.1%) were categorized at the low level, 50 students (65.8%) were in the medium category, and 13 students (17.1%) achieved a high level. This distribution highlights that the majority of students are situated at the medium level, with relatively few students showing very low or very high levels of critical thinking. In other words, although most students can show certain aspects of critical thinking, only a few are able to reach the higher levels of critical thinking when solving geometry problems

Research Question 2: What difficulties do students encounter when applying mathematical critical thinking in solving geometry problems?

Students' ability to demonstrate critical thinking skills was analysis through a students' responses for the mathematical critical thinking test. The following is example of students' responses to one of the critical thinking questions.

Question 1: A total of 850 liters of water will be poured into a rectangular tank with dimensions $125\ cm \times 100\ cm\ \times 80\ cm$. Will the water overflow? Give your reasons!

This question engaged students' critical thinking skills, as they needed to interpret the relationship between liters and cubic centimeters, analyse by calculating the tank's capacity, and then evaluate whether the given volume of water would exceed that capacity and justifying their reasoning.

The following results were presented from the selected respondents' work.

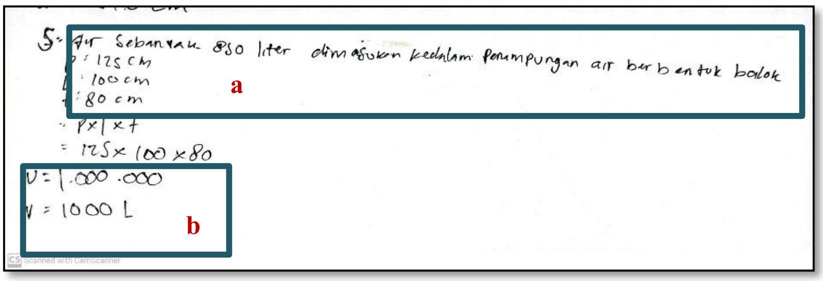

Figure 1. Respondent 1 answer to question 1

Based on Figure 1, Respondent 1 began by correctly identifying the given information, as shown in (a). The student recognized the relevant dimensions (125 cm × 100 cm × 80 cm) and attempted to calculate the volume by multiplying them. This demonstrates that the student was able to determine the necessary information for solving the problem and apply the volume formula for a rectangular prism. Furthermore, the student recalled and used the conversion between cubic centimetres and litters, as shown in (b). This indicates that the decoding process emerged, as the student successfully translated between two different units of measurement. However, the interpreting category only partially appeared because the student did not fully clarify the main problem goal, namely comparing the tank's capacity with the amount of water poured. The analysing category was evident only to a limited extent, R1 correctly applying the formula and reached 1000 L capacity but didn't explicitly connect it to the 850 L of water, while the evaluating category did not appear at all, where R1 stopped after calculation. No judgment or justification was written R1 did not state whether the tank would overflow. The results show that R1 could apply the formula correctly but had trouble thinking beyond that step. R1 struggled to connect the information given in the problem and to draw a clear final conclusion.

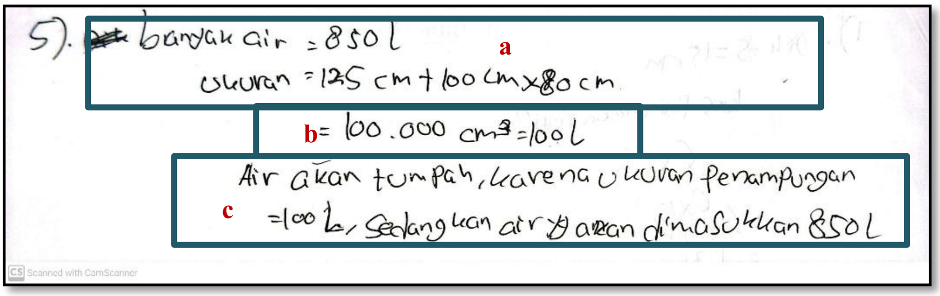

Figure 2. Respondent 2 answer to question 1

Based on Figure 2, Respondent 2 began by correctly identifying the dimension and the water amount, as shown in (a). In addition, the decoding process was appeared as R2 recognized the need to convert 100.000 cm^3 to litter as shown in (b). This indicates that R2 clearly understood which information was relevant. Furthermore, R2 demonstrated the analysing process but made an arithmetic mistake that led to wrong inference. R2 applied the volume formula to solve the question, however R2 mis converted the unit by writing 100.000 cm^3 = 100 L. As a result, R2 inferred the capacity (100 L) is smaller than water poured (850 L). In the evaluation category, R2 judged the tank would overflow and justified this by comparing 100 L vs 850 L as shown in (c). Therefore, the final judgment is wrong, it is based on an earlier computational error.

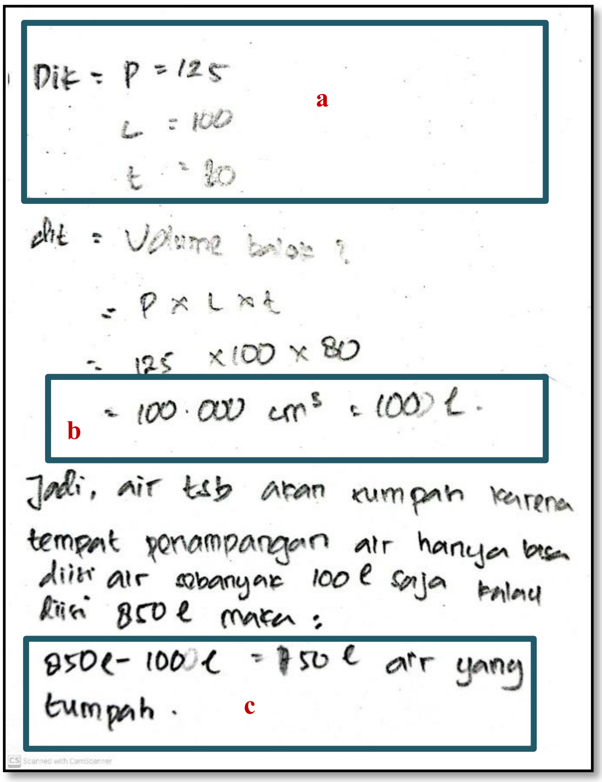

Figure 3. Respondent 3 answer to question 1

Figure 3 shows Respondent 3's answer to Question 1. R3 began by correctly identifying the tank's dimensions and the amount of water, as shown in (a). The decoding process was also evident when R3 recognized the need to convert 100,000 cm³ to liters, as shown in (b). This indicates that R3 clearly understood what the question required. However, during the analysing stage, R3 made an arithmetic error that led to an incorrect inference. Although R3 correctly applied the volume formula, they misconverted the unit by writing 100,000 cm³ = 100 L instead of 1,000 L as shown in (b). As a result, R3 inferred that the tank's capacity was 100 L and compared it with 850 L of water, even calculating the overflow volume as 850 − 100 = 750 L as shown in (c) . In the evaluation stage, R3 made a clear judgment by writing "*air akan tumpah*" (the water will overflow). However, because this judgment was based on an earlier calculation error, the final claim is invalid.

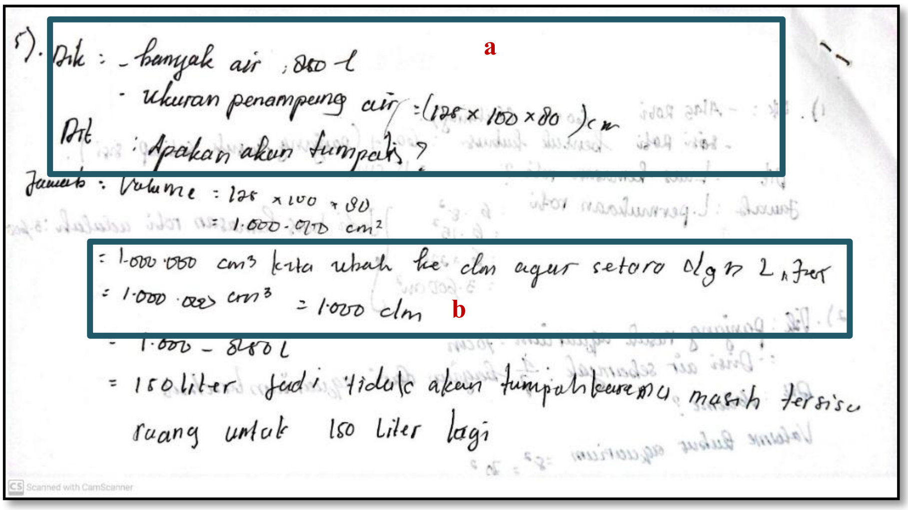

Figure 4. Respondent 4 answer to question 1

Figure 4 shows Respondent 4's answer to Question 1. R4 correctly identified the tank's dimensions and the amount of water as shown in (a). The decoding process was also evident when R4 recognized the need to convert 100,000 cm^3 to liters as shown in (b), showing a complete understanding of the interpreting stage. Furthermore, R4 demonstrated a clear and meaningful analysing process by correctly applying the formula, performing accurate conversions, and inferring that the tank's capacity was 1,000 L while the amount of water poured was 850 L. In the evaluation stage, R4 concluded that the water would not overflow and justified this with quantitative reasoning, writing "*masih tersisa ruang 150 L*" (there is still 150 L of space), which is mathematically correct. However, R4 made a small error in unit notation by writing "1000 dm" without the cube as shown in (b). This minor mistake indicates that R4 understood the concept correctly but misrepresented the unit symbol.

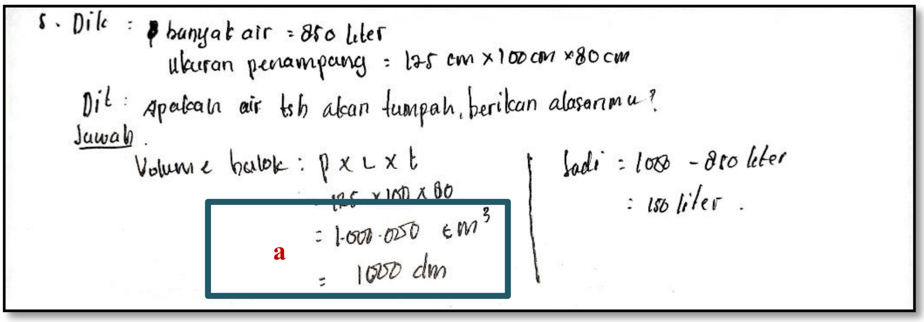
5. Dik : banyak air = 850 liter
ukuran penampang : 125 cm × 100 cm × 80 cm
Dit : Apakah air tsb akan tumpah, berikan alasanmu?
Jawab.
Volume balok : p × l × t
= 125 × 100 × 80
= 1.000.000 cm³
= 1000 dm
Jadi : 1000 − 850 liter
: 150 liter.
a

Figure 5. Respondent 5 answer to question 1

Figure 5 shows Respondent 5's answer to Question 1. Similar to R4, R5 clearly answered the question by demonstrating all indicators of critical thinking. R5 also made a minor notation error by writing "1000 dm" without the cube as shown in (a) Additionally, in the evaluation stage, R5 did not explicitly state the verbal conclusion such as "*Maka, air tidak akan tumpah karena masih ada sisa 150 liter ruang*" (Therefore, the water will not overflow because there is still 150 liters of space). Overall, both R4 and R5 showed good understanding with only minor errors related to unit notation and conclusion expression.

DISCUSSION

The findings indicate that students demonstrated a moderate level of critical thinking ability, indicating that many students are still not yet reached a consistently high level of performance. This result align with the study conducted by Sari & Caswita (2020), which found that students' critical thinking skills still need further improvement.

Furthermore, the main difficulties students encountered when applying mathematical critical thinking in solving geometry problems were related to reasoning coherence, unit representation, and the formulation of conclusions. Although some students (e.g., R1) were able to apply the correct formula, they struggled to conceptually connect the given information and to draw a logical final conclusion. This finding is consistent with Fineldi (2023), who reported that students often experience confusion in writing or concluding during the encoding process. Similarly, Sodik, Hendriana, Supriatna, & Putra (2025) identified weaknesses in students' analytical and argumentative reasoning, while Angkotasan, Suharna, Abdullah, & Dahlan (2024) found that students encountered difficulties in evaluating the problem-solving process.

Other students (e.g., R3) demonstrated the ability to make evaluative judgments; however, these were often influenced by earlier computational or unit-conversion errors, which resulted in invalid conclusions. This is in line with the study by Febriyanti, Wahyuddin, & Mutaminnah (2024), which revealed that students frequently make both conceptual and operational errors. Conceptual misunderstandings such as those related to the meaning of volume or the characteristics of shapes often lead to more substantial mistakes. Even students who made fewer errors still struggled with unit conversion. Additionally, findings from Tasya Aprilla Trisna, Ikhsan, & Elizar (2022) support this, indicating that students often have difficulty maintaining precision in calculations and correctly applying formulas during geometric transformations, resulting in procedural errors.

In contrast, students such as R4 and R5 generally demonstrated a sound understanding of concepts and computational steps. Nevertheless, minor issues remained, including the misrepresentation of unit symbols and the absence of explicit verbal conclusions. This observation aligns with (Ramdjid, Sukestiyarno, Rochmad, & Mulyono, 2022), who found that students often provided incomplete responses when solving geometry problems. Overall, these results suggest that while students can perform procedural computations, they face challenges in integrating interpretation, analysis, and evaluation coherently, which are essential dimensions of mathematical critical thinking.

These findings may also be associated with instructional practices in geometry that do not sufficiently emphasize conceptual understanding. Research on teaching approaches (Sujero & Alcuizar, 2025) has shown that different teaching strategies significantly influence students' conceptual understanding in geometry, and that when instruction does not actively engage students with conceptual reasoning, their conceptual understanding remains unsatisfactory. Findings from literature reviews also highlight that research in geometry education often focuses on procedural aspects of mathematical thinking while potentially overlooking deeper conceptual reasoning processes that support students' ability to integrate interpretation and evaluation in problem solving (Fachrudin & Juniati, 2023). This may explain why some students in this study were able to perform procedural calculations but failed to present explicit conclusions or coherent explanations reflecting higher levels of mathematical critical thinking.

CONCLUSION AND SUGGESTIONS

The findings indicate that students mathematical critical thinking skills in in moderate level. The main difficulties students encountered when applying mathematical critical thinking in solving geometry problems were related to reasoning coherence, unit representation, and conclusion formulation. Although some students were able to apply the correct formula, they struggled to connect the given information conceptually and to draw a logical final conclusion. In addition, students demonstrated the ability to make evaluative judgments, but these were often based on earlier computational or reasoning errors, which led to invalid conclusions.

Furthermore, students showed a generally good grasp of the concept and computation steps, yet minor issues persisted, including misrepresentation of unit symbols and the lack of explicit verbal conclusions. These findings suggest the need for geometry instruction that places greater emphasis on conceptual reasoning, explicit justification, and reflection, rather than procedural fluency alone. Future research is recommended to employ in-depth interviews to gain deeper insights into students' mathematical critical thinking processes and the sources of their difficulties.

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