

ANALYSIS OF STUDENTS' MATHEMATICAL CONCEPTUAL UNDERSTANDING IN SOLVING HOTS-BASED CIRCLE PROBLEMS AT AN ISLAMIC BOARDING SCHOOL

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ABSTRACT

This study aims to explore in depth students' mathematical conceptual understanding in solving Higher Order Thinking Skills (HOTS) problems on the topic of circles and to identify the error patterns and problem-solving strategies that emerge in an Islamic boarding school context. Mathematics learning in Islamic boarding schools presents unique challenges because students are required to balance academic learning with intensive religious and boarding-school activities, which may influence their learning experiences and conceptual understanding. The study employed a qualitative descriptive design supported by quantitative descriptive statistics. The participants were nine twelfth-grade students from a pesantren-based senior high school in Indramayu, who completed a HOTS-based conceptual understanding test and semi-structured interviews. Data were analyzed through the stages of reduction, presentation, and conclusion drawing, with source triangulation used to ensure data credibility. The results showed that 22% of students were classified in the high category, 56% in the medium category, and 22% in the low category, with an average score of 53 and a standard deviation of 26. Students in the high category were able to determine circle equations, center points, radii, intersection points, and visual representations accurately. In contrast, students in the medium category experienced difficulties in elimination, factorization, and visualization processes, while students in the low category struggled with algebraic operations and substitution procedures. These findings indicate that most students still require support in applying conceptual understanding to HOTS-based contextual problems. This study contributes to mathematics education by providing an in-depth description of students' conceptual understanding, error patterns, and problem-solving strategies when solving HOTS-based circle problems in an Islamic boarding school setting.

Keywords: HOTS; boarding school students; circles; understanding of mathematical concepts.

ABSTRAK

Penelitian ini bertujuan mengungkap tingkat pemahaman konsep matematis siswa pesantren dalam menyelesaikan soal Higher Order Thinking Skills (HOTS) pada materi lingkaran serta memetakan karakter kesalahan dan strategi penyelesaian yang digunakan. Penelitian menggunakan pendekatan deskriptif kualitatif yang didukung analisis deskriptif kuantitatif dengan subjek sembilan siswa kelas XII pada salah satu SMA berbasis pesantren di Indramayu. Pengelompokan siswa ke dalam kategori tinggi, sedang, dan rendah dilakukan berdasarkan indikator pemahaman konsep matematis yang meliputi kemampuan menyatakan kembali konsep, merepresentasikan konsep, menerapkan prosedur, dan menyelesaikan masalah. Data dikumpulkan melalui enam soal uraian kontekstual dan wawancara semiterstruktur. Instrumen penelitian telah melalui proses validasi ahli sebelum digunakan. Data dianalisis melalui tahap reduksi, penyajian, dan penarikan kesimpulan dengan triangulasi sumber. Hasil penelitian menunjukkan bahwa 22% siswa berada pada kategori tinggi, 56% kategori sedang, dan 22% kategori rendah, dengan rata-rata skor 53 dan simpangan baku 26 yang menunjukkan adanya variasi kemampuan dan heterogenitas pemahaman konsep di antara siswa. Siswa kategori

tinggi mampu menentukan persamaan lingkaran, pusat, jari-jari, posisi titik, dan titik potong kurva secara tepat. Siswa kategori sedang masih mengalami kesulitan pada proses eliminasi, pemfaktoran, dan visualisasi, sedangkan siswa kategori rendah mengalami kesulitan pada operasi aljabar dasar dan substitusi. Temuan ini menunjukkan bahwa sebagian besar siswa masih memerlukan penguatan pemahaman konsep untuk menyelesaikan soal HOTS secara efektif. Oleh karena itu, diperlukan strategi pembelajaran yang dapat memperkuat penalaran aljabar, kemampuan visualisasi, dan pemahaman konsep matematis guna meningkatkan kemampuan siswa dalam menyelesaikan soal HOTS.

Kata kunci: HOTS; kelompok; pemahaman konsep matematika; siswa sekolah asrama;



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Introduction

Mathematics plays a crucial role in education because it develops students' logical, systematic, critical, and analytical thinking skills. (Amir, 2016) states that mathematics occupies a substantial portion of instructional time in schools, while, (Yanala et al., 2021) describe mathematics as a symbolic language used to study patterns, relationships, and problem-solving in daily life. Therefore, mathematics learning emphasizes not only computational skills but also conceptual understanding, which enables students to connect mathematical ideas, interpret relationships among concepts, and apply knowledge in various contexts (Yang et al., 2021; Yulia & Nasution, 2022). Students with strong conceptual understanding are better able to analyze situations, evaluate arguments, and construct solution strategies when facing unfamiliar problems. Consequently, conceptual understanding is regarded as a prerequisite for higher-order thinking processes, including reasoning, critical thinking, and problem solving (Nurhidayat et al., 2023; Fauziyah & Hakim, 2025). However, empirical evidence indicates that students still experience difficulties in connecting mathematical concepts, interpreting representations, and applying reasoning in non-routine problems Simarmata et al., (2022). Similarly, Herman et al., (2022) reported that weaknesses in conceptual understanding and mathematical reasoning often hinder students' higher-order thinking performance. These findings highlight the importance of strengthening conceptual understanding to support meaningful learning and higher-order mathematical thinking.

Understanding mathematical concepts is a fundamental skill in mathematics education because it helps students think logically and systematically when solving problems (Aryani & Maulida, 2019). A common problem in mathematics is a lack of student interest in understanding mathematical (Arif, et al., 2025). However, many students still rely on memorizing formulas without understanding the underlying concepts, which often leads to difficulties when solving problems that differ from previously learned examples (Rismawati & Hutagaol, 2018). In this study, it was found that students who have visual, auditory and kinesthetic learning styles have different ways of solving problems (Nungrum et al., 2025). This indicates that students' conceptual understanding remains a challenge in mathematics learning. Although previous studies have examined students' difficulties in understanding mathematical concepts, limited attention has been given to how students with different ability levels demonstrate conceptual understanding when solving Higher Order Thinking Skills (HOTS) problems, particularly on circle-related

material in pesantren-based schools. Therefore, this study investigates students' mathematical conceptual understanding across different ability categories and identifies the error characteristics that emerge in solving HOTS problems on circles.

Understanding mathematical concepts involves students' ability to restate concepts, classify objects, select appropriate procedures, and apply concepts to solve problems. Hanifah and Abadi (2018) explain that indicators of mathematical concept understanding include the ability to restate concepts, classify objects based on specific properties, present concepts in various mathematical representations, use specific procedures, and apply concepts in daily life. However, (Simarmata et al., 2022) found that many students are still unable to restate concepts correctly and have difficulty connecting mathematical concepts to the problem-solving process. These findings indicate that students' conceptual understanding remains relatively low.

Mathematics education increasingly emphasizes the development of Higher Order Thinking Skills (HOTS), which involve analyzing, evaluating, and creating solutions to problems. Noprinda and Soleh (2019) explain that HOTS questions can foster students' critical and creative thinking skills in mathematics learning. In addition, Herman et al., (2022) found that HOTS questions can improve students' reasoning and reflective thinking skills. Therefore, solving HOTS problems requires not only procedural knowledge but also strong conceptual understanding. One mathematical topic suitable for assessing HOTS is circles because it requires students to integrate geometric concepts, interpret representations, and apply reasoning in unfamiliar situations. However, students frequently experience difficulties in understanding and applying circle concepts, particularly those involving relationships among radius, diameter, circumference, area, and coordinate geometry (Aprilia et al., 2024). Consequently, circle-related problems provide an appropriate context for assessing students' higher-order thinking and conceptual understanding.

In the context of pesantren-based schools, mathematics education presents unique challenges because the learning process emphasizes not only mastery of academic content but also the integration of Islamic values. This situation requires students to balance formal academic learning with intensive religious and boarding-school activities. Previous studies have indicated that the pesantren environment influences students' learning experiences, motivation, and learning habits, which may affect their understanding of mathematical concepts and problem-solving performance (Hidayati et al., 2024). Moreover, mathematics learning in pesantren is often expected to be connected with students' daily experiences and religious contexts, creating distinctive characteristics that differ from those of general schools (Ramdhani et al., 2023). Therefore, the ability to understand mathematical concepts and solve Higher Order Thinking Skills (HOTS) problems is a critical aspect that must be prioritized in mathematics education at pesantren-based schools. One area of mathematics that requires these abilities is the study of circles, as it involves interconnected concepts and demands analytical reasoning for problem-solving.

Several studies have examined students' conceptual understanding, Higher Order Thinking Skills (HOTS), and mathematical reasoning in mathematics learning. Previous research shows that students often experience difficulties in explaining concepts, connecting mathematical ideas, and applying knowledge in unfamiliar

situations (Komariyah et al., 2018; Simarmata et al., 2022). Furthermore, conceptual understanding has been recognized as an important foundation for mathematical reasoning and higher-order thinking (Yang et al., 2021; Nurhidayat et al., 2023). Furthermore, conceptual understanding has been recognized as an important foundation for mathematical reasoning and higher-order thinking (Noprinda & Soleh, 2019; Herman et al., 2022). However, most studies have examined conceptual understanding, reasoning, and HOTS separately and have rarely focused on circle-related material in pesantren-based schools. Therefore, further investigation is needed to understand how students demonstrate conceptual understanding and what error patterns emerge when solving HOTS problems on circles.

Recent studies have highlighted the importance of mathematical conceptual understanding and Higher Order Thinking Skills (HOTS) in supporting students' success in mathematics learning. Research conducted within the last five years has shown that conceptual understanding is closely related to students' ability to reason, solve complex problems, and engage in higher-order thinking processes (Yang et al., 2021; Nurhidayat et al., 2023). Similarly, studies on HOTS have emphasized the need for students to integrate conceptual knowledge with analytical and evaluative thinking when solving mathematical problems (Herman et al., 2022; Aprilia et al., 2024). However, existing studies have generally examined conceptual understanding, mathematical reasoning, or HOTS separately and have mostly been conducted in general school settings. Consequently, limited research has specifically investigated students' mathematical conceptual understanding when solving HOTS problems on circle-related material within pesantren-based schools. In addition, the characteristics of students' errors in solving HOTS-oriented circle problems remain underexplored. These gaps indicate the need for further research to provide a more comprehensive understanding of students' conceptual understanding and problem-solving processes in this particular educational context. Table 1 presents a gap analysis of previous studies and highlights the differences between existing research and the current study.

Table 1. Gap Analysis of Previous Studies and the Current Research

Previous Study	Research Focus	Main Findings	Research Gap
Komariyah et al. (2018)	Mathematical conceptual understanding	Students had difficulty explaining mathematical concepts they had learned.	Did not examine conceptual understanding in solving HOTS problems, particularly on circle-related material.
Simarmata et al. (2022)	Connections among mathematical concepts in problem solving	Students frequently made errors when connecting mathematical concepts during problem solving.	Did not analyze students' conceptual understanding based on HOTS tasks or investigate error characteristics in depth.

Noprinda and Soleh (2019)	HOTS questions and critical thinking skills	HOTS questions contributed to the development of students' critical thinking skills.	Focused on HOTS outcomes without specifically examining mathematical conceptual understanding.
Herman et al. (2022)	HOTS questions and mathematical reasoning	HOTS questions improved students' mathematical reasoning abilities.	Did not investigate how conceptual understanding supports students in solving HOTS problems.
Current Study	Mathematical conceptual understanding in solving HOTS problems on circles in pesantren-based schools	Analyzes students' levels of conceptual understanding and identifies error patterns when solving HOTS problems on circle-related material.	Addresses the limited research integrating conceptual understanding, HOTS problem solving, and error analysis within the context of pesantren-based schools.

The comparison presented in Table 1 shows that previous studies have generally examined mathematical conceptual understanding and Higher Order Thinking Skills (HOTS) separately and were mostly conducted in regular school settings. Limited attention has been given to students' conceptual understanding and error patterns when solving HOTS problems on circle-related material, particularly in pesantren-based schools. Therefore, this study investigates students' mathematical conceptual understanding and identifies error patterns in solving HOTS problems on circles within this educational context.

This study analyzed students' performance on HOTS problems using indicators of mathematical conceptual understanding, including the ability to restate concepts, classify objects according to their properties, represent concepts mathematically, apply appropriate procedures, and solve problems. Through these indicators, the study aimed to determine students' levels of conceptual understanding and identify error patterns that emerged during the problem-solving process. The findings are expected to provide insights into students' understanding of circle-related concepts and support the development of more effective mathematics learning strategies in pesantren-based schools.

Solving HOTS-based circle problems requires students not only to recall formulas but also to understand conceptual relationships, interpret mathematical representations, and apply appropriate reasoning strategies. Therefore, conceptual understanding is a crucial foundation for successful problem solving. In pesantren-based schools, where students balance academic and religious learning activities, investigating conceptual understanding in HOTS situations is important for identifying learning needs and challenges. Accordingly, this study aims to analyze students' levels of mathematical conceptual understanding in solving HOTS problems on circles and to identify the error characteristics that emerge during the

problem-solving process. The findings are expected to contribute to mathematics education by providing insights for teachers, curriculum developers, and educational policymakers in improving mathematics learning in pesantren-based schools.

Research Methods

This study employed a qualitative descriptive approach supported by quantitative descriptive analysis to analyze students' understanding of mathematical concepts in solving Higher Order Thinking Skills (HOTS) problems on the topic of circles. The qualitative descriptive approach served as the primary research design to explore students' conceptual understanding and identify error characteristics through written responses and interviews (Doyle et al., 2020), while quantitative descriptive analysis was used to calculate students' test scores and classify them into high, medium, and low categories of conceptual understanding. Students were categorized based on the mean and standard deviation of the test scores, after which one representative student from each category was selected purposively for in-depth interviews. Therefore, the study was not designed as a mixed-methods study, as the quantitative data were used solely to support participant categorization and facilitate deeper qualitative analysis. Qualitative descriptive research aims to describe and analyze phenomena comprehensively based on field data (Amalia & Hadi, 2020; Furidha, 2023) and systematically present findings according to the conditions observed during the research process (Rohman et al., 2020).

The study was conducted at a pesantren-based senior high school in Indramayu Regency and involved all nine twelfth-grade students in the class. All students completed a HOTS-based mathematical conceptual understanding test on circle-related material. Test scores were analyzed using the mean and standard deviation and classified into high, medium, and low categories based on Azwar's criteria (Azwar, 2012, as cited in (Pebriana & Imami, 2024). as presented in Table 2. Subsequently, one student from each category was selected purposively for interviews based on the representativeness of the category, completeness of written responses, and willingness to participate. As a result, three students representing different levels of conceptual understanding were analyzed in depth to explore their problem-solving processes and error characteristics in solving HOTS problems on circles.

Table 2. Classification Criteria for Mathematical Conceptual Understanding

Score Interval	Category
$X \geq (M+1SD)$	High
$(M-1SD) \leq X < (M+1SD)$	Medium
$X < (M-1SD)$	Low

As shown in Table 2, students were classified into three levels of mathematical conceptual understanding based on the distribution of their test scores. This classification was used to identify students with different levels of conceptual understanding and served as the basis for selecting interview participants. One student from each category was subsequently chosen to represent the characteristics of the category during the in-depth qualitative analysis.

The variable analyzed in this study was students' mathematical conceptual understanding in solving HOTS problems on the topic of circles. The research instruments consisted of test and non-test instruments. The test instrument comprised six open-ended HOTS questions adapted from Amri (2022) and designed to measure students' conceptual understanding of circles. Minor modifications were made to the wording of several items to suit the characteristics of students in a pesantren-based school while maintaining the original HOTS indicators and content. The questions were developed using two contexts: earthquake scenarios (Questions 1–4) and asteroid trajectory scenarios (Questions 5–6). Before implementation, the instrument was validated by three mathematics education experts, consisting of two lecturers from the Mathematics Education Department at IAIN Metro and one mathematics teacher from SMAN 1 Punggur. The validation process assessed content relevance, HOTS indicators, language clarity, and item suitability, and the results indicated that all six items met the validity criteria. Subsequently, students' written responses and interview data were coded based on conceptual understanding indicators and analyzed to identify patterns of problem-solving strategies and error characteristics.

The non-test instruments consisted of a semi-structured interview guide used to explore students' thought processes in solving HOTS problems. Interviews were conducted with three students representing high, moderate, and low levels of mathematical conceptual understanding after the written test (Muniroh & Buchori, 2024). The interview guide contained questions prepared by the researchers to confirm and clarify students' written responses (Hasanah & Pujiastuti, 2023). Data analysis involved coding responses based on conceptual understanding indicators, identifying patterns of solution strategies and errors, and grouping similar findings into categories and themes. The interview findings were then compared with the written test results to determine whether students' explanations supported, clarified, or contradicted their written responses. For example, some students obtained partially correct answers but were unable to explain the underlying concepts during interviews, while others were able to clarify incomplete written responses. This process enhanced the credibility of the findings through source triangulation.

Data were collected through written tests and interviews. The written tests assessed students' mathematical conceptual understanding in solving HOTS problems, while interviews were conducted to validate the findings and explore students' thought processes. Prior to data collection, the researcher obtained official permission from the university and the school, and the study was conducted in accordance with research ethics principles. Participants' identities were kept confidential, and all data were used solely for research purposes.

Data analysis followed the Miles and Huberman model, consisting of data reduction, data presentation, and conclusion drawing. Data reduction involved selecting and grouping test and interview data according to the research focus. The data were then presented in tables and narrative descriptions to facilitate interpretation, and conclusions were drawn based on students' conceptual understanding in the high, medium, and low categories.

Data validity was established through source triangulation. According to Ruwaida (2018), source triangulation involves comparing data from different

sources to enhance credibility. In this study, students' written test results were compared with interview findings to ensure the consistency and validity of the data.

Results and Discussion

The research results were obtained from an analysis of students' responses to Higher Order Thinking Skills (HOTS)-based mathematics problems on the topic of circles. The collected data were classified according to students' levels of mathematical conceptual understanding into high, medium, and low categories. The distribution of students' mathematical conceptual understanding is presented in Table 3.

Table 3. Categories of Mathematical Conceptual Understanding

Response to Statement Type	Category	Score	Total	Percentage
$X \geq (M+1SD)$	High	$X \geq 79$	2	22%
$M-1SD) \leq X < (M+1SD)$	Medium	$28 \leq X < 79$	5	56%
$X < (M-1SD)$	Low	$X < 28$	2	22%

Based on Table 3, most students were classified in the medium category (56%), while 22% were categorized as high and 22% as low. This finding indicates that most students had acquired basic conceptual knowledge but experienced difficulties when applying concepts to solve HOTS problems requiring analysis, evaluation, and strategy selection. According to conceptual understanding theory, students who possess strong conceptual understanding are able to connect mathematical ideas, interpret relationships among concepts, and apply concepts flexibly in unfamiliar situations. Therefore, the dominance of students in the medium category suggests that many students have not yet fully developed the conceptual structures necessary for higher-order thinking and mathematical reasoning. Students in the high category generally demonstrated systematic and accurate solution strategies, whereas students in the low category experienced difficulties in understanding circle concepts and applying appropriate problem-solving procedures.

To provide a general overview of students' performance on the HOTS-based conceptual understanding test, a summary of students' test scores is presented in Table 4.

Table 4. Summary of Student Test Scores

Number of Students	Highest Score	Lowest Value	Standard Deviation	On average
9	93	7	26	53

As shown in Table 4, the average student score was 53, with scores ranging from 7 to 93 and a standard deviation of 26. The relatively high standard deviation indicates substantial variation in students' conceptual understanding and their ability to solve HOTS problems. Based on Bloom's Revised Taxonomy, HOTS tasks require students to engage in cognitive processes of analysis, evaluation, and creation rather than merely recalling formulas or procedures. Consequently, students with stronger conceptual understanding were better able to reason, select appropriate solution strategies, and justify their answers, whereas students with

weaker conceptual understanding tended to rely on memorized procedures and experienced difficulties when confronted with unfamiliar problem situations. These findings support previous studies indicating that conceptual understanding serves as an important foundation for higher-order thinking and mathematical reasoning. Table 5. Comparison of Conceptual Understanding Indicators Across Categories

Indicator of Conceptual Understanding	High Category	Medium Category	Low Category
Restating concepts	Achieved consistently	Partially achieved	Frequently incorrect
Classifying objects according to their properties	Achieved correctly	Some errors observed	Significant difficulties
Representing concepts mathematically	Accurate and complete	Partially accurate	Often incomplete
Applying procedures appropriately	Systematic and correct	Correct but inconsistent	Frequently incorrect
Applying concepts to solve HOTS problems	Flexible and successful	Limited success	Significant difficulties

Table 5 shows clear differences in conceptual understanding across achievement categories. Students in the high category demonstrated mastery of all conceptual understanding indicators and were able to apply concepts flexibly when solving HOTS problems. In contrast, students in the medium category generally understood basic concepts but encountered difficulties when applying these concepts to unfamiliar situations. Meanwhile, students in the low category showed weaknesses across several indicators, particularly in representing concepts and applying concepts to solve HOTS problems. These findings indicate that students' success in solving HOTS problems is closely related to the depth of their conceptual understanding.

Analysis of Mathematical Conceptual Understanding in HOTS Questions

The analysis of the research results was conducted based on six HOTS questions on the topic of circles. Each question was analyzed according to students' levels of mathematical conceptual understanding, namely high, medium, and low categories. The analysis focused on students' ability to understand concepts, apply mathematical procedures, reason logically, and solve contextual problems requiring higher-order thinking skills. The HOTS problem used in Questions 1–4 is presented in Figure 1.



Figure 1. HOTS Problem A: Earthquake Context

In a BMKG laboratory, a researcher is analyzing areas affected by earthquakes with a magnitude of less than 5. Based on satellite images and earthquake applications, it is known that the earthquake's impact area is relatively extensive. Therefore, the researcher maps the affected area onto a Cartesian coordinate plane (x, y) . Village A is located at coordinates $(30, -10)$, Village B at $(-40, -20)$, and Village C at $(30, 50)$. All three villages experienced the earthquake tremors. Based on this information, students were required to solve a series of HOTS problems involving circle equations, center points, radii, and geometric reasoning. Figure 1 illustrates the contextual problem used to assess students' conceptual understanding and problem-solving abilities in circle-related HOTS tasks.

Can you help the researcher solve the problem they are facing? If the researcher estimates the range of the vibration to be r km using the equation of a circle: $x^2 + y^2 + Ax + By + C = 0$, then help the researcher answer the following questions:

Question 1 (Determining the Equation of a Circle)

In this problem, students were asked to determine the equation of a circle based on three given points. Using the information provided, students were required to formulate a mathematical model and determine the equation representing the earthquake vibration area. The written response of a student in the high-achievement category is presented in Figure 2.

- High-Achieving Students' Answers

The written response of the high-achieving student in determining the equation of a circle is presented in Figure 2.

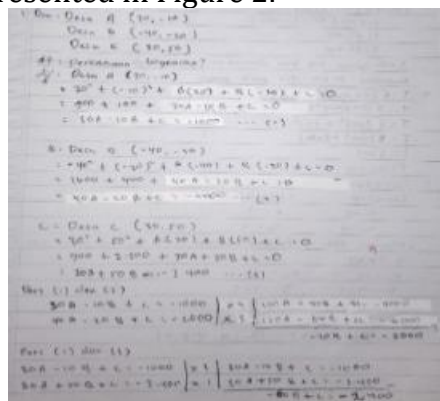


Figure 2. Students' Answers

Based on Figure 2, the high-achieving student was able to correctly formulate the equation of the earthquake's circular wave using the coordinates of Village A $(30, -10)$, Village B $(-40, -20)$, and Village C $(30, 50)$. The student demonstrated an understanding of the general form of a circle equation, $x^2 + y^2 + Ax + By + C = 0$, and systematically substituted the three points to construct a system of linear equations. The student then applied the elimination method accurately and obtained $A = -120$, $B = -100$, and $C = -2000$, resulting in the circle equation $x^2 + y^2 - 120x - 100y - 2000 = 0$. Figure 2 illustrates that the student was able to connect geometric concepts with algebraic procedures and organize the solution process logically. During the interview, the student stated that determining the equation of the circle was not difficult but admitted to occasionally making computational errors due to a lack of focus. This finding indicates that the student

possessed strong conceptual understanding and was able to apply appropriate problem-solving strategies, although greater attention to computational accuracy is still needed.

- Student Answers: Moderate Level

The written response of the student in the medium category in determining the equation of a circle is presented in Figure 3.

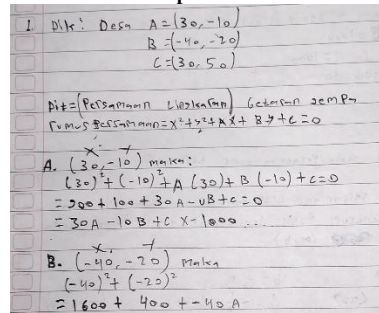


Figure 3. Students' Answers

Based on Figure 3, the student in the medium category demonstrated an initial understanding of the general form of the circle equation, $x^2 + y^2 + Ax + By + C = 0$, and attempted to substitute the coordinates of the given points into the equation. The student successfully formulated a complete equation for Village A (30, -10) and began constructing the equation for Village B (-40, -20), but the solution process was incomplete and did not proceed to the elimination stage required to determine the values of A, B, and C. Figure 3 indicates that the student understood the basic concepts involved in the problem but experienced difficulties in organizing a complete system of linear equations and applying algebraic procedures accurately. During the interview, the student explained that determining the equations and performing the elimination process were the most challenging parts of the task. This finding suggests that the student possessed partial conceptual understanding but lacked procedural fluency in algebraic manipulation. Consequently, reinforcement of algebraic reasoning and systematic problem-solving strategies is needed to support students in solving HOTS-based circle problems more effectively.

- Student Responses: Low Category

The written response of the student in the low category in determining the equation of a circle is presented in Figure 4.

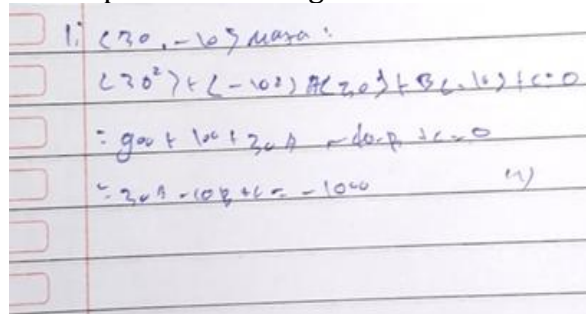


Figure 4. Students' Answers

Students in the lower performance category demonstrated initial efforts to formulate the equation of a circle using the coordinate point (30, -10), but the solutions they presented were still very limited and incomplete. Students attempted

to write the general form of the equation $x^2 + y^2 + Ax + By + C = 0$ and substitute values for x and y , but were only able to formulate a single equation without proceeding to other points or to the stage of eliminating the system of equations. This indicates that students' understanding of the concepts and procedures for formulating circle equations remains low. In interviews, students admitted to having difficulty formulating the equation of a circle as a whole, indicating that they have not yet mastered the basic steps in solving coordinate-based geometry problems, particularly in the context of Higher-Order Thinking Skills (HOTS). Further instruction should focus on understanding the basic concepts of the equation of a circle and systematic practice in formulating and solving systems of equations.

The findings of Question 1 indicate clear differences in students' conceptual understanding across achievement levels. Students in the high category were able to connect the concept of circle equations with systems of linear equations and apply appropriate solution strategies, whereas students in the medium and low categories experienced difficulties in constructing complete mathematical models and carrying out algebraic procedures. Although some students in the medium category were able to complete parts of the solution process correctly, interview results revealed that they often experienced uncertainty when determining equations and performing elimination procedures. This finding suggests that procedural success does not necessarily indicate genuine conceptual understanding. Students may arrive at partially correct solutions by following memorized procedures without fully understanding the relationships among the mathematical concepts involved. In contrast, students with stronger conceptual understanding were able to explain their reasoning, justify the procedures used, and connect known information to unknown variables systematically. These findings are consistent with Simarmata et al. (2022), who reported that students often struggle to connect mathematical concepts when solving non-routine problems. Similar findings have also been reported in other educational contexts, where students experience difficulties in translating geometric situations into algebraic representations and integrating multiple concepts simultaneously when solving HOTS problems. From the perspective of conceptual understanding theory, students with well-developed conceptual structures are better able to construct mathematical models and solve problems flexibly, whereas students with weaker conceptual understanding tend to rely on isolated procedures, resulting in incomplete or incorrect solutions.

Question 2: (Finding the Center of a Circle)

In this problem, students are asked to determine the center of the circle.

- High-Achieving Students' Answers

The written response of the high-achieving student in determining the center of the circle is presented in Figure 5.

<input type="checkbox"/>	2. titik pusat ?
<input type="checkbox"/>	$a = \frac{1}{2} a$ $b = \frac{1}{2} b$
<input type="checkbox"/>	$= \frac{1}{2} (20)$ $= \frac{1}{2} (40)$
<input type="checkbox"/>	$= 10$ $= 20$
<input type="checkbox"/>	

Figure 5. Students' Answers

High-performing students were able to accurately determine the epicenter of an earthquake using the midpoint formula, namely $\frac{1}{2} \times 20 = 10$ dan $\frac{1}{2} \times 40 = 20$, demonstrating a strong understanding of the concept of coordinates and how to apply it in the context of earthquakes. In interviews, students stated that determining the epicenter was relatively easy, provided they understood how to solve the first problem. This reflects that students not only mastered the procedure but also possessed logical problem-solving strategies that progressed consistently from one stage to the next.

- Student Answers: Moderate Level

The written response of the student in the medium category in determining the center of the circle is presented in Figure 6.

$a = -\frac{1}{2} A$	$b = \frac{1}{2} B$
$a = -\frac{1}{2} (20)$	$b = -\frac{1}{2} (-40)$
$a = \frac{1}{2} a$	$b = \frac{1}{2} b$
$= \frac{1}{2} (20)$	$= \frac{1}{2} (-40)$
$= -10$	$= -20$

Figure 6. Students' Answers

Students in the intermediate category demonstrated a basic understanding of determining the epicenter of an earthquake using the midpoint formula; however, their calculations and writing of the formula appeared inconsistent and somewhat confusing, such as the use of repetitive notation and untidy placement of variables. Nevertheless, the students were able to arrive at the correct final result, namely the midpoint of the two coordinates. In interviews, students stated that the question felt somewhat confusing because the information provided was considered unclear, indicating that students need more guidance in understanding contextual information and filtering important data from complex questions.

- Student Responses: Low Category

The written response of the student in the low category in determining the center of the circle is presented in Figure 7.

2. $a = \frac{1}{2} A$ $b = \frac{1}{2} b$

Figure 7. Students' Answers

Students in the low-performing category only wrote down the general formula for the epicenter, $a = \frac{1}{2}A$ and $b = \frac{1}{2}B$ without proceeding to substitute values or complete the calculation, indicating that their understanding of the concept of the epicenter is still very limited. In interviews, students admitted to being confused because they felt they lacked a general understanding of mathematics, indicating the presence of fundamental conceptual barriers as well as a lack of confidence in solving problems. This highlights the need for a more concrete, step-by-step, and contextual learning approach to build students' foundational mathematical understanding and skills.

Question 3: (Finding the Radius of a Circle)

In this problem, students are asked to determine the maximum distance (the radius of the circle).

- High-Achieving Students' Answers

The written response of the high-achieving student in determining the radius of the circle is presented in Figure 8.

Handwritten work for Figure 8:

$$\begin{aligned} \text{Jadi: } r &= \sqrt{(-10)^2 + (20)^2 - (-2000)} \\ r &= \sqrt{100 + 400 - (-2000)} \\ r &= \sqrt{2500} \\ r &= 50 \text{ km} \end{aligned}$$

Handwritten conclusion: "Jadi gempa tsb bisa dirasakan getarannya apabila bergerak maksimal 50 km dari pusat gempa"

Figure 8. Students' Answers

High-performing students were able to solve the problem by correctly applying the formula for the distance between two points, namely $r = \sqrt{(-10)^2 + (20)^2 - (-2000)} = \sqrt{2500} = 50 \text{ km}$, and then concluded that the earthquake could be felt up to a maximum distance of 50 km from the epicenter. In interviews, students stated that they did not experience any confusion because they used a valid formula, demonstrating confidence and a good understanding of the concept. This reflects higher-order thinking skills, where students can relate mathematical calculations to the context of the problem and verify their answers logically.

- Student Answers: Moderate Level

The written response of the student in the medium category in determining the radius of the circle is presented in Figure 9.

Handwritten work for Figure 9:

$$\begin{aligned} r &= \sqrt{(-10)^2 + (20)^2 - (-2000)} \\ &= \sqrt{100 + 400 - (-2000)} \\ &= \sqrt{500 + 2000} \\ &= \sqrt{2500} = 50 \text{ km} \end{aligned}$$

Figure 9. Students' Answers

Students in the intermediate category demonstrated a basic understanding of the concept of distance by using the formula $r = \sqrt{(-10)^2 + (20)^2 - (-2000)} =$ and successfully calculated the final result: $r = \sqrt{2500} = 50 \text{ km}$. However, although the final result is correct, the calculation process contains conceptual errors, namely

a misunderstanding of the formula's structure and the addition/subtraction operations within the square root, which should not incorporate constant values from outside the context of the distance formula. In the interview, the student admitted to being unsure about the result of the calculation because they often lack focus. This reflects that the student is at an intermediate ability level, where they understand the general steps but are still not thorough and confident in verifying the accuracy of their calculations.

- Student Responses: Low Category

The written response of the student in the low category in determining the radius of the circle is presented in Figure 10.

$$r = \sqrt{(-10)^2 + (20)^2} - c$$

$$= \sqrt{100 + 400 - (-2000)}$$

Figure 10. Students' Answers

Students in the low-performing category demonstrated a limited understanding of the concept of distance, as evidenced by their use of an incorrect formula—namely, $\sqrt{(-10)^2 + (20)^2} - c$ —and subsequent confusing calculations, such as $100 + 400 - (-2000)$, which indicate an error in illogically integrating the constant c into the distance formula. In interviews, students admitted to being unsure of their calculations because they often lacked focus, reflecting a lack of confidence and difficulty in understanding and applying correct mathematical concepts. This indicates that students still need intensive guidance to strengthen their foundational understanding and improve their concentration when working on problems.

Question 4 (Determining the Magnitude of an Earthquake)

In this question, students are asked to determine whether a point lies within the circle's radius. If the point is located in Village D, which has coordinates (10, 35) on the map, will the point feel the tremors from the earthquake?

- High-Achieving Students' Answers

The written response of the high-achieving student in determining the position of a point relative to the circle is presented in Figure 11.

$$4. \quad T = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$$

$$T = \sqrt{(10 - (-10))^2 + (35 - 20)^2}$$

$$T = \sqrt{(20)^2 + (15)^2}$$

$$T = \sqrt{400 + 225}$$

$$T = \sqrt{625}$$

$$T = 25 \text{ km}$$

Figure 11. Students' Answers

High-performing students were able to solve the problem correctly using the formula for the distance between two points, as shown by the calculation $\sqrt{(10 - (-10))^2 + (35 - 20)^2} = \sqrt{400 + 225} = \sqrt{625} = 25 \text{ km}$. He demonstrated a good conceptual understanding in determining whether Village D felt the earthquake by comparing the calculated distance with the maximum radius of the tremor. In the interview, the student stated that he was confident in his answer and used "felling" as a form of intuition based on the comparison of distances. He did not

feel confused because the strategy he used was appropriate, namely calculating the distance and comparing it with the maximum distance of the earthquake.

- Student Answers: Moderate Level

The written response of the student in the medium category in determining the position of a point relative to the circle is presented in Figure 12.

Figure 12. Students' Answers

The student in the intermediate category demonstrated a fairly good understanding by applying the formula for the distance between two points, $T = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$ to calculate $T = 25$ km; however, he was unsure about selecting the epicenter and therefore still relied on his “gut feeling” when answering. In the interview, he admitted to being unsure during the stage of determining the earthquake’s epicenter coordinates and felt confused because he did not fully understand how to establish the epicenter before calculating the distance, even though the distance calculation itself was correct.

- Student Responses: Low Category

The written response of the student in the low category in determining the position of a point relative to the circle is presented in Figure 13.

Gambar 13. Jawaban Siswa

Students in the low-performing category demonstrated a weak understanding of the concept of the distance between two points. This was evident in their errors when deriving the formula, where they incorrectly wrote and calculated $(10 - (-10))^2$ as $10 - 100$, which is mathematically incorrect. Consequently, the calculation becomes illogical, resulting in $\sqrt{-90 + 225}$, which should not occur if the steps were correct. In the interview, the student admitted to experiencing difficulty and confusion while working on the problem, as well as lacking a clear strategy. This indicates that the student still requires guidance in understanding the basic concept of distance and the proper application of mathematical formulas.

Read the following problem B carefully to answer questions 5 and 6!

To further analyze students’ mathematical conceptual understanding in a different context, Questions 5 and 6 used a HOTS problem related to the predicted collision between an asteroid and a satellite. The problem required students to apply concepts of circles, lines, systems of equations, and mathematical visualization

to solve contextual situations. The HOTS problem used in Questions 5 and 6 is presented in Figure 14.



Figure 14 HOST Question

Asteroid 2001 CA21 is reported to make a close pass by Earth on March 4, 2022. According to Newsweek on Friday (February 4, 2022), asteroid 138971—also known as asteroid 2001 CA21—has a diameter of 1.3 kilometers, or 4,265 feet. If compared to an object, this asteroid is about four times the height of the Eiffel Tower. The asteroid is predicted to approach Earth with the equation $y - x - 7 = 0$ and is said to have a speed of 26,800 miles per hour. NASA states that, although it will pass very close to Earth, there is no cause for concern regarding asteroid 2001 CA21. Although classified as a potentially hazardous asteroid by NASA’s Center for Near-Earth Object Studies (CNEOS), asteroid 2001 CA21 is not expected to collide with Earth. However, the asteroid is predicted to collide with a satellite orbiting Earth with the equation $x^2 + y^2 - 25 = 0$. Assuming the point (0,0) is the Earth’s center and if such a collision were to occur, can you help NASA find:

Question 5: (Finding the Intersection Point of a Line and a Circle)

In this problem, students are asked to determine the point of intersection between a line and a circle. How do you determine the coordinates of the point of collision between an asteroid and an Earth satellite? Solve this using mathematical calculations!

- High-Achieving Students' Answers

The written response of the high-achieving student in determining the intersection points between the asteroid’s trajectory and the satellite’s orbit is presented in Figure 15.

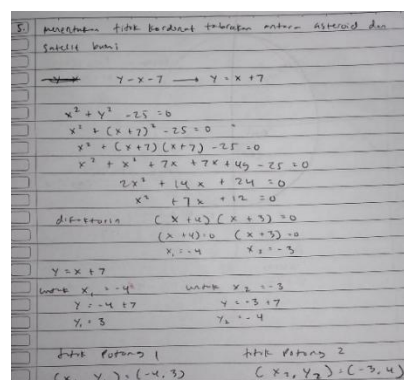


Figure 15. Students' Answers

High-achieving students are able to solve problems correctly by following systematic mathematical steps. They transform the equation of the line $y = x - 7$ into the explicit form $y = x + 7$, then substitute it into the equation of the circle $x^2 + y^2 = 25$ to find the intersection points of the asteroid’s trajectory and the satellite’s orbit. The student correctly outlined the steps one by one, starting

from substitution, simplification, and factoring the quadratic equation, to finding the two collision points, namely $(-4,3)$ and $(-3,4)$. In an interview, the student stated that although the problem text was understandable, he needed more time to grasp the context of the story provided. This indicates that the student possesses strong mathematical analysis and reasoning skills, as well as perseverance in understanding the context of real-world problems before applying mathematical concepts appropriately.

- Student Answers: Moderate Level

The written response of the student in the medium category in determining the intersection points between the asteroid's trajectory and the satellite's orbit is presented in Figure 16.

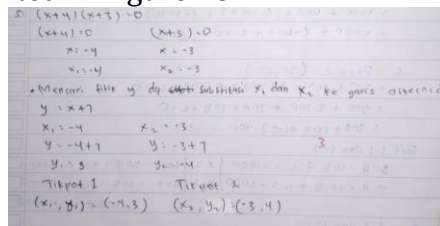


Figure 16. Students' Answers

Students in the intermediate category were able to solve the problem to find the coordinates of the intersection points, namely $(-4,3)$ and $(-3,4)$, using a fairly logical sequence of steps. Students factored the quadratic equation resulting from the substitution and found two values of x , then substituted them into the equation of the asteroid line to obtain the value of y . Although the steps were correct, the students appeared to be merely following a pattern without fully explaining the initial substitution process, such as the transformation and simplification of the equation forms from the two curves. In interviews, students stated that this problem was confusing, indicating difficulty in understanding the problem context or connecting the story to mathematical forms. This suggests that although students have sufficient operational understanding, they still need reinforcement in conceptual understanding and the application of real-world contexts to mathematical models.

- Student Responses: Low Category

The written response of the student in the low category in determining the intersection points between the asteroid's trajectory and the satellite's orbit is presented in Figure 17.

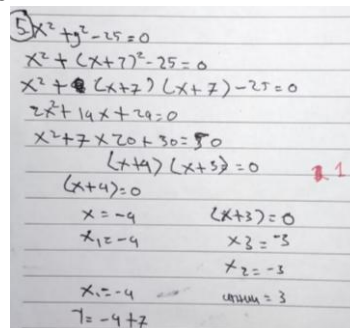


Figure 17. Students' Answers

The low-performing student demonstrated considerable difficulty in understanding and solving the problem, despite attempting to outline several solution steps. From the written response, it is evident that the student attempted

to substitute the line equation $y = x + 7$ into the circle equation $x^2 + y^2 = 25$; however, errors occurred during algebraic manipulation and factorization, resulting in an incorrect final answer. The interview data revealed that the student perceived the problem as confusing and difficult, suggesting limited understanding of the relationship between the line and circle equations. A closer examination of the student's work indicates that the difficulties were not limited to computational errors but also involved weaknesses in algebraic reasoning. The student struggled to perform substitution correctly, simplify algebraic expressions, and factor quadratic equations, all of which are essential steps in determining the intersection points of a line and a circle. These findings suggest that the student lacked a coherent understanding of how algebraic procedures are connected to the underlying geometric concepts. Consequently, errors in substitution and factorization prevented the student from constructing a complete mathematical model and reaching a valid solution. This result highlights the important role of algebraic competence in solving HOTS-based circle problems, as weaknesses in fundamental algebraic skills can hinder students' ability to apply mathematical concepts effectively in complex problem-solving situations.

Question 6: (Problem Visualization)

In this question, students are asked to draw an illustration of the problem. Redraw problem B using an illustration based on your understanding!

- High-performing students' answers

The written response of the high-achieving student in visualizing the collision between the asteroid and the satellite is presented in Figure 18.

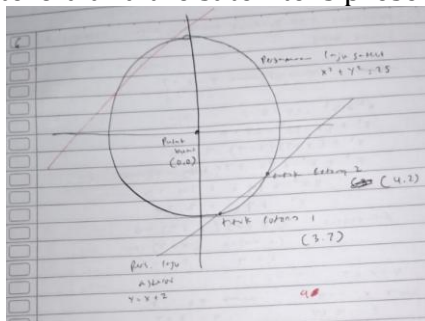


Figure 18. Students' Answers

High-performing students successfully illustrated the scenario of a collision between an asteroid and a satellite quite well, as evidenced by their ability to draw a circle representing the satellite's orbit with its center at the point (0,0) and a line representing the asteroid's trajectory. Students listed the equations for each object, namely $x^2 + y^2 = 25$ for the orbit and $y = x + 2$ for the asteroid's path, and labeled the intersection points, which were assumed to be the collision points. Nevertheless, in interviews, students revealed that drawing such illustrations was quite difficult because they were not accustomed to it and rarely practiced visualization-based problems. This indicates that students have the ability to understand and apply mathematical concepts in a visual context, but still need more practice in converting verbal information into graphical representations.

- Student Answers: Moderate Level

The written response of the student in the medium category in visualizing the collision between the asteroid and the satellite is presented in Figure 19.

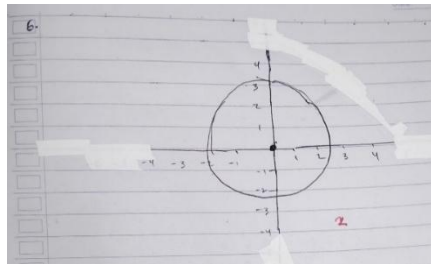


Figure 19. Student Responses

Based on Figure 19, the student in the medium category was able to represent the satellite's orbit as a circle centered at the point $(0,0)$, indicating a basic understanding of the key elements involved in the problem. However, the student did not include the asteroid's trajectory or the intersection points, suggesting difficulties in integrating mathematical information into a complete visual representation. Figure 19 shows that although the student recognized some essential components of the problem, the relationships among those components were not represented comprehensively. Interview results revealed that the student found the visualization process challenging because of difficulties in imagining the relationships among the objects described in the problem. This finding indicates that the student's conceptual understanding was still partial, as individual elements could be identified but their mathematical relationships could not be represented accurately. A possible cause of this difficulty is the limited opportunity students have had to engage with visualization-based and contextual geometry tasks. Consistent with previous studies, students often experience difficulties when transforming verbal and symbolic information into visual representations. These findings suggest that mathematical visualization plays an important role in supporting conceptual understanding, as students who are unable to construct accurate visual representations may also experience difficulties in understanding relationships among mathematical concepts and solving HOTS problems effectively.

- Student Responses: Low Category

The written response of the student in the low category in visualizing the collision between the asteroid and the satellite is presented in Figure 20.

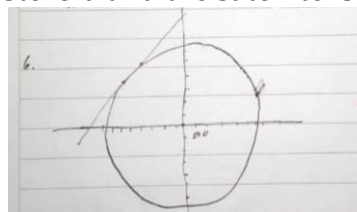


Figure 20. Students' Answers

Based on Figure 20, students in the low category attempted to represent the collision between an asteroid and a satellite using simple sketches of circles and lines. However, the drawings lacked important elements such as clear intersection points and labels, indicating limited understanding of the mathematical relationships involved. Interview results showed that students experienced difficulties in transforming mathematical information into visual representations. This finding suggests that the difficulty was not merely related to drawing skills but

also to conceptual understanding, as students struggled to connect verbal information, symbolic representations, and geometric relationships. Similar difficulties were also observed among some high-achieving students, although to a lesser extent. These findings highlight the important role of mathematical visualization in supporting conceptual understanding and HOTS performance, particularly in solving contextual geometry problems.

Overall, the findings indicate that students' mathematical conceptual understanding in solving HOTS problems on circles was predominantly at the medium level. Most students were able to recall basic concepts and perform routine procedures but experienced difficulties in analyzing contextual information, constructing mathematical models, and integrating multiple concepts. These difficulties were particularly evident in tasks involving algebraic manipulation and mathematical visualization. The findings from Question 6 suggest that visualization is closely related to conceptual understanding, as students who could accurately represent relationships among mathematical objects generally demonstrated a better understanding of the underlying concepts. Conversely, students who struggled with visualization often had difficulty connecting verbal information, symbolic representations, and geometric relationships. Interview data supported this finding, indicating that students were often able to identify individual elements of a problem but struggled to integrate them into a complete mathematical representation.

The findings are consistent with Simarmata et al. (2022), who reported that students often experience difficulties in connecting mathematical concepts during problem solving, and with Noprinda and Soleh (2019), who found that HOTS problems require strong conceptual understanding. However, this study extends previous findings by showing that students' difficulties also involve algebraic reasoning and mathematical visualization. In particular, students in the medium and low categories experienced difficulties in manipulating algebraic expressions and solving circle-related problems, indicating that success in HOTS tasks depends not only on conceptual understanding but also on supporting algebraic skills.

The findings imply that mathematics instruction should provide greater opportunities for students to engage in contextual and higher-order thinking activities. Approaches such as Problem-Based Learning (PBL), inquiry-based instruction, and visualization-supported learning can help students strengthen conceptual understanding while simultaneously developing mathematical reasoning and HOTS. Through these approaches, students are encouraged to construct mathematical models, explore relationships among concepts, justify their reasoning, and represent mathematical situations visually. Therefore, the results of this study contribute to the growing body of research emphasizing that conceptual understanding, algebraic reasoning, and visualization skills are interconnected components that support students' success in solving HOTS problems on circle-related material.

Conclusion and Suggestion

Based on the findings, students' mathematical conceptual understanding in solving Higher Order Thinking Skills (HOTS) problems on the topic of circles was generally at the medium level. High-achieving students were able to apply

mathematical concepts systematically in determining circle equations, center points, radii, intersection points, and visual representations, whereas students in the medium and low categories experienced difficulties in understanding concepts, performing algebraic procedures, and visualizing mathematical situations. The findings suggest that stronger conceptual understanding is associated with better performance in HOTS problems requiring reasoning, modeling, and visualization. Furthermore, the study highlights the importance of conceptual understanding, algebraic reasoning, and mathematical visualization as interconnected components in solving circle-related HOTS problems.

The results also indicate that HOTS-based tasks can be used to identify students' conceptual understanding, reasoning, and mathematical representation skills more deeply. Therefore, mathematics teachers are encouraged to implement contextual and HOTS-oriented learning strategies, such as Problem-Based Learning, mathematical modeling, inquiry-based instruction, and visualization-supported learning, to strengthen students' conceptual understanding and higher-order thinking skills. Future studies may investigate other mathematical topics or explore the effectiveness of specific instructional approaches in improving students' HOTS performance.

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