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Improving Mathematical Reasoning Through Geogebra-Assisted Discovery Learning

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ABSTRACT

This study aims to improve the mathematical reasoning ability of Grade XI students through the implementation of GeoGebra-assisted discovery learning. The research employed a classroom action research design conducted in two cycles, each consisting of the stages of planning, implementation, observation, and reflection. The participants were 40 Grade XI students at SMA Negeri 8 Padang, and the learning material focused on geometric transformations. The main research instrument was an essay test developed based on indicators of mathematical reasoning ability. Data were analyzed by examining the average test scores and learning completeness in each cycle. The results showed that the application of GeoGebra-assisted discovery learning successfully improved students' mathematical reasoning skills. This improvement was indicated by an increase in the average test score from 63.15% in Cycle I to 81.22% in Cycle II. In addition, learning completeness increased from 55% in Cycle I to 80% in Cycle II, thereby meeting the predetermined success indicator of at least 70% of students achieving improvement. Discovery-based learning supported by GeoGebra encouraged students to actively observe patterns, formulate conjectures, examine arguments, and draw conclusions through direct visual exploration. These findings suggest that the integration of technological media into active learning models can foster deeper, more logical, and more structured mathematical reasoning processes. Therefore, GeoGebra-assisted discovery learning is effective in enhancing the mathematical reasoning ability of Grade XI students.

Keywords*: *mathematical reasoning ability, geogebra, discovery learning model, classroom action research

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INTRODUCTION

Mathematics plays an important role in the advancement of science and technology. Through mathematics learning, students' thinking skills are trained to think critically, analytically, innovatively, and creatively in order to face the dynamics of the times and technological developments. The importance of these higher-order thinking skills is also emphasized in Permendikdasmen No. 10 of 2025 concerning Graduate Competency Standards in Early Childhood Education, Primary Education, and Secondary Education, which states that one of the dimensions of the graduate profile that must be achieved is reasoning. The NCTM (2000) has established five basic standards of mathematical ability, namely problem solving, reasoning and proof, communication, connection, and representation.

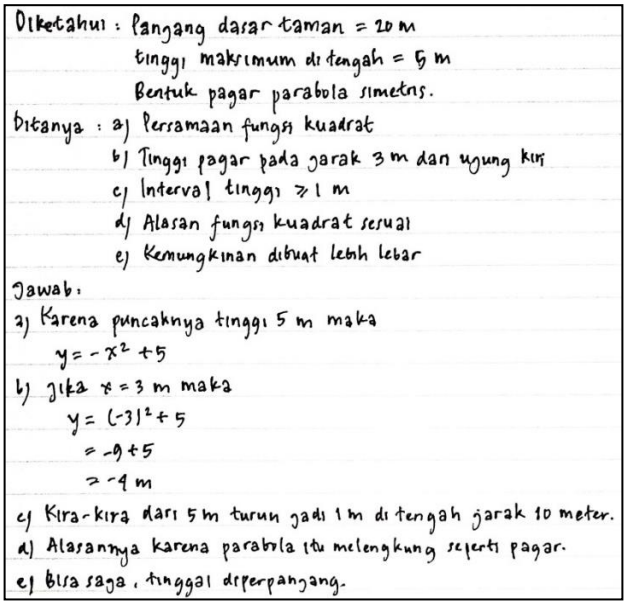
Mathematical reasoning is understood as a thought process in drawing conclusions from statements whose truth is already known (Ningsih, 2021; Nabila, 2022). Mathematics and mathematical reasoning ability are two closely related aspects. Reasoning is needed to solve mathematical problems, while reasoning ability can be honed through learning mathematics (Suharti, 2021; Syahnaz, 2021; Kusumaningtyas, 2022). Therefore, mathematical reasoning ability is essential and necessary in mathematics learning, particularly as a foundation for students to justify solutions, construct arguments, and make valid conclusions.

However, in practice, students' mathematical reasoning abilities have not yet reached an optimal level and still require improvement (Endrawati, 2021; Fatimah, 2021; Jusmawati, 2021; Yustinaningrum, 2022). This condition is reinforced by the results of the TIMSS in 2011, which placed Indonesia 38th out of 42 countries with an average score of 386. The pass rate for mathematical reasoning skills among Indonesian

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students was only 17%, far below the international average pass rate of 30% (Kurniawati, 2021). Similarly, based on the PISA 2018, Indonesian students' mathematical reasoning skills remain relatively low (Nurazizah, 2022).

The low level of mathematical reasoning ability is also reflected in the findings of Sumarsih (2018), Jumiarsih (2020), and Harapit (2021), which show that students' passive tendencies in reasoning negatively affect learning outcomes. Students often experience difficulties in constructing proofs, performing mathematical manipulations, and drawing conclusions, leading them to provide answers without first making assumptions (Siregar, 2016). A similar situation was found among grade XI students at SMA Negeri 8 Padang when they were given mathematical reasoning problems.



Translation:
Given:
Base length of the garden = 20 m.
Maximum height in the center = 5 m.
Symmetrical parabolic fence shape.
Questions:
a) Quadratic function equation
b) Fence height at a distance of 3 m from the left end
c) Height interval ≥ 1 m
d) Reason for quadratic function
e) Possibility of making it wider
Answer:
a) Because the peak is 5 m high, then
$y = -x^2 + 5$
b) If $x = 3$ m then
$y = (-3)^2 + 5$
$= -9 + 5$
$= -4$ m
c) Approximately from 5 m down to 1 m in the middle of a distance of 10 m.
d) The reason is because the parabola curves like a fence.
e) It is possible, just extend it.

Figure 1. Student Responses

Based on Figure 1, it was evident that students were unable to represent problems mathematically in a complete and accurate manner. The absence of diagrams or sketches, incorrect assumptions regarding coordinate systems, and the tendency to directly write equations without testing or verifying parameters indicate weaknesses in making conjectures, operating mathematical models, and evaluating results. Students tended to draw conclusions intuitively without verification, failed to recheck illogical results, and did not utilize properties of mathematical objects such as symmetry or parameter relationships. These findings illustrate deficiencies in core components of mathematical reasoning, including assumption-making, justification, verification, and generalization.

These weaknesses are influenced by several factors, including limited exposure to reasoning-based problems, restricted learning time, and low student motivation (Fedistia, 2020; Ningsih, 2021; Oktaviana, 2021). Furthermore, students' passive attitudes toward critical thinking exacerbate the situation (Jumiarsih, 2020; Harapit, 2021). The abstract nature of geometry material presents an additional challenge, as students often struggle to reason about objects they cannot easily visualize (Ramadhani, 2016; Kusuma, 2017;

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Wulandari, 2020). This condition highlights the need for learning strategies that actively engage students in constructing meaning and reasoning processes.

One learning model that aligns with the development of mathematical reasoning is the discovery learning model (Haeruman, 2017; Yerizon, 2018; Fitriyana, 2020). Discovery learning emphasizes active learning through independent discovery and investigation, enabling knowledge to be retained longer in students' memory (Hosnan, 2014). In this model, students are required to actively discover mathematical concepts or principles through exploration and inquiry (Adelia, 2017).

The stages of discovery learning-stimulation, problem statement, data collection, data processing, verification, and generalization-are closely related to the indicators of mathematical reasoning. Through these stages, students are trained to formulate assumptions, explore relationships, test hypotheses, justify solutions, and draw conclusions systematically. Thus, discovery learning is not only focused on concept acquisition but also on fostering structured reasoning processes that are essential in mathematics learning. Previous studies have shown that discovery learning can improve conceptual understanding (Romadon, 2019), mathematical reasoning skills (Fadli, 2019; Zubainur, 2020; Meiliputri, 2021), mathematical communication (Arifin, 2018), and mathematical problem-solving abilities (Nasution, 2019; Hakim, 2021). These findings support the suitability of discovery learning as an instructional approach for improving students' mathematical reasoning.

In addition to selecting an appropriate learning model, integrating technology into mathematics learning is also crucial for strengthening students' reasoning skills. Mathematical objects, particularly in geometry, are often abstract and difficult for students to conceptualize (Hanafi, 2017; Anggraeni, 2020; Utami, 2020; Sari, 2021). Visualization is therefore essential to support students in exploring relationships, testing conjectures, and verifying conclusions. Technology-based learning has been shown to positively influence guided discovery (Jupri, 2018; Jelatu, 2018; Lestari, 2018; Nurjanah, 2020), academic achievement (Horzum, 2017; Hussin, 2018; Alkhateeb, 2019), attitudes, motivation (Zengin, 2017; Radovic, 2020; Rabi, 2021), independent learning (Jusufi, 2019; Nurhayati, 2019), problem solving (Kusuma, 2017; Wassie, 2019; Celen, 2020; Tong, 2021), mathematical communication (Asryana, 2017; Zetriuslita, 2019), and spatial thinking (Zengin, 2019; Fikriah, 2021).

GeoGebra is a dynamic and interactive software that is particularly suitable for supporting mathematical reasoning (Maravillas, 2019; Rahmat, 2019) because it allows students to manipulate mathematical objects and observe changes in real time (Ngwabe, 2020; Acikgul, 2021). As a visualization and demonstration tool (Alves, 2019; Maulyda, 2019; Pamungkas, 2020), GeoGebra enables students to explore multiple representations simultaneously through algebraic, graphical, 3D, and statistical views (Septian, 2020; Juandi, 2021). This dynamic environment encourages students to make conjectures based on observed patterns, test assumptions by modifying parameters, and verify results logically.

By utilizing GeoGebra, students can construct geometric objects accurately, explore relationships through manipulation, evaluate the correctness of their representations, and investigate mathematical properties directly (Syahbana, 2016). These activities directly support key components of mathematical reasoning, such as making assumptions, providing justification, evaluating solutions, and drawing valid conclusions. Previous research confirms that GeoGebra creates a dynamic learning environment (Celen, 2020; Rabi, 2021), enhances conceptual understanding and motivation (Ocal, 2017), and facilitates visualization in geometry learning (Mawarsari, 2017; Wulandari, 2020). Therefore, integrating GeoGebra within the discovery learning model is expected to provide a coherent and effective approach to improving students' mathematical reasoning abilities.

METHOD

This study employed a classroom action research design consisting of two cycles, each comprising four stages: planning, action implementation, observation, and reflection. This design was selected to allow for continuous improvement of the learning process and to clearly identify changes in students' mathematical

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reasoning abilities from one cycle to the next. The instructional intervention focused on the application of the GeoGebra-assisted discovery learning model in geometric transformation topics.

Research Setting and Participants

The research was conducted in grade XI.F7 at SMA Negeri 8 Padang, involving 40 students (16 male and 24 female). The study was carried out during the July–December 2025 semester in mathematics lessons covering translation, reflection, rotation, and dilation. During the planning stage, learning tools were prepared, including teaching modules, student worksheets, GeoGebra-based learning media, as well as research instruments such as test blueprints and scoring rubrics for mathematical reasoning ability.

Implementation of Actions

The learning actions in both cycles followed the syntax of the discovery learning model, namely stimulation, problem identification, data collection, data processing, verification, and conclusion drawing. GeoGebra was utilized throughout the learning process to facilitate dynamic visualization and manipulation of geometric objects, enabling students to explore transformation concepts and test conjectures visually.
However, the implementation in Cycle II was not a mere repetition of Cycle I. Based on the reflection results from Cycle I, several pedagogical adjustments were made in Cycle II. In Cycle I, some students experienced difficulties in formulating initial assumptions, operating GeoGebra independently, and providing logical justifications for their conclusions. Students also tended to rely on trial-and-error manipulation without systematically verifying their results. To address these issues, Cycle II incorporated the following improvements:

1. Strengthening the stimulation and problem identification stages by providing guiding questions that explicitly prompted students to make assumptions and predict outcomes before using GeoGebra.
2. More structured worksheets that guided students step-by-step in exploring transformations, recording observations, and linking visual changes to algebraic representations.
3. Explicit scaffolding in the verification stage, where students were required to explain why a result was valid based on geometric properties rather than visual appearance alone.
4. Increased teacher facilitation and feedback, particularly in supporting students' use of GeoGebra and encouraging peer discussion to evaluate and refine arguments.
5. Emphasis on conclusion drawing and generalization, where students were guided to identify patterns and formulate general rules derived from their explorations.
6. These adjustments were intended to enhance students' engagement in the reasoning process and to ensure that each stage of discovery learning effectively contributed to the development of mathematical reasoning skills.

Data Collection Techniques

The primary data collection instrument was a mathematical reasoning test consisting of essay questions administered at the end of each meeting in each cycle. The test items were constructed based on indicators of mathematical reasoning, including presenting mathematical statements, making assumptions, performing mathematical manipulations, providing reasons or evidence, checking the validity of arguments, drawing conclusions, and identifying patterns for generalization. Supporting data were obtained through classroom observations and documentation, including field notes, student worksheets, and records of GeoGebra-based activities.

Data Analysis

The test results were analyzed quantitatively by calculating the percentage of students' mathematical reasoning achievement using the following formula:

$$\text{Percentage} = \frac{\text{The total score obtained by the student}}{\text{Maximum score}} \times 100\%$$

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The study was considered successful if at least 70% of students demonstrated an improvement in mathematical reasoning ability at the end of the cycle.

Reflection Stage

The reflection stage involved a systematic comparison of the results from Cycle I and Cycle II to identify improvements and remaining challenges. The findings from Cycle I reflection were used as the basis for revising instructional strategies in Cycle II. The final reflection focused on evaluating the effectiveness of the GeoGebra-assisted discovery learning model in improving students' mathematical reasoning ability and determining whether the success criteria had been achieved.

RESULTS AND DISCUSSION

This classroom action research was conducted in two cycles, each consisting of four stages, namely planning, implementation, observation, and reflection. The research was conducted on 40 students in class XI.F7 at SMA Negeri 8 Padang. Data on mathematical reasoning abilities were collected through descriptive tests at the end of each cycle using indicators such as presenting mathematical statements, making assumptions, performing mathematical manipulations, constructing reasons or evidence, checking the validity of arguments, drawing conclusions, and finding patterns to make generalizations.

Cycle I Results

Cycle I was implemented using the discovery learning model for translation and reflection material with the support of GeoGebra media. Based on the mathematical reasoning test results, the average score of the students reached 63.15%. Of the 40 students, only 22 students (55%) obtained a score of ≥ 70. Learning activities showed that some students were still not optimally operating the GeoGebra features so that several indicators of proposing hypotheses and checking arguments had not developed optimally. In addition, group discussions were not balanced because there were students who were still passive.

Cycle II Results

In cycle II, improvements were made in the form of more structured guidance, the addition of GeoGebra step-by-step instructions to the worksheets, and the provision of simple visual exploration examples at the beginning of the lesson. The material used was rotation and dilation. The mathematical reasoning test results showed an increase in the average score to 81.22%. The number of students who scored ≥ 70 increased to 32 students (80%). Observations showed significant progress in the indicators of making assumptions, checking the validity of arguments, and drawing conclusions. Students were able to verify the results of visual manipulation with manual calculations and draw generalizations from transformation patterns.

Figure 2 shows a graph of the increase in the average mathematical reasoning ability of students in each cycle of classroom action research. In cycle I, the average score for students' mathematical reasoning ability was 63.15%. This value indicates that some students were able to present mathematical statements, perform simple manipulations, and provide reasons for their answers, but were not yet optimal in making assumptions, checking the validity of arguments, and making generalizations. This condition is in line with the initial findings of the study, which indicated that learning with a conventional approach did not fully provide space for students to explore their thinking.

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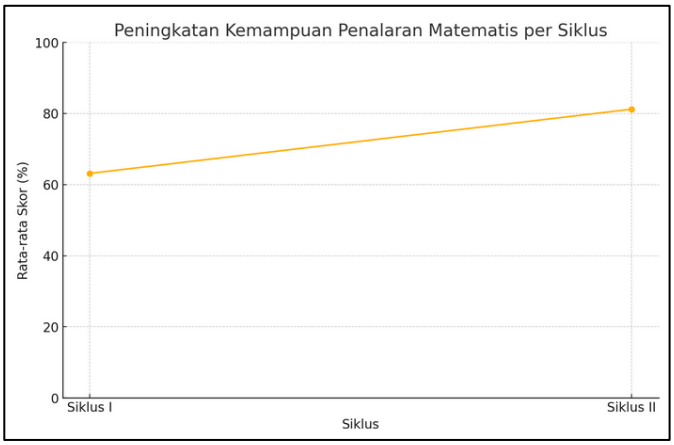


Figure 2. Graph of Improvement in Mathematical Reasoning Ability per Cycle

After improvements were made in cycle II through the use of a more structured LKPD, guidance on the use of GeoGebra features, and improved discussion quality in accordance with discovery learning syntax, the average score increased to 81.22%. The graph shows a significant increase of 18.07 points from cycle I to cycle II. It means that most students were able to identify transformation patterns, verify the results of visual exploration with manual calculations, and draw logical conclusions.

This improvement shows that discovery-based learning and digital visualization can build high-level mathematical thinking skills. Discovery learning allows students to discover mathematical patterns themselves through observation and hypothesis testing (Hosnan, 2014), while GeoGebra helps simplify abstract objects into visual representations that are easy to manipulate (Syahbana, 2016). Thus, the use of the GeoGebra-assisted discovery learning model has proven effective in making assumptions, checking the validity of arguments, and generalizing concepts.

Discussion

The findings of this study demonstrate that the application of the GeoGebra-assisted discovery learning model positively influenced the mathematical reasoning abilities of grade XI students at SMA Negeri 8 Padang. The improvement was not merely reflected in numerical gains—such as the increase in the average test score from 63.15% in Cycle I to 81.22% in Cycle II and the rise in learning mastery from 55% to 80%—but also in qualitative changes in how students reasoned mathematically.

A deeper analysis reveals that the most challenging reasoning indicators for students in Cycle I were making assumptions, providing logical justification, and drawing valid conclusions. Students tended to apply procedural steps mechanically without first predicting outcomes or explaining why a solution was correct. This difficulty aligns with earlier observations that students often struggle to construct arguments and verify results logically (Siregar, 2016). In Cycle II, however, notable improvements occurred in these indicators, suggesting that the learning intervention addressed not only surface-level understanding but also core reasoning processes.

The improvement in students' reasoning can be explained by the interaction between the structured stages of discovery learning and the dynamic feedback provided by GeoGebra. The discovery learning model required students to engage in a sequence of reasoning activities—formulating hypotheses, testing assumptions, verifying results, and generalizing findings—which are central to mathematical reasoning. This supports Hosnan's (2014) view that discovery learning places students at the center of cognitive activity, allowing knowledge to be constructed meaningfully and retained longer. Through repeated engagement in these stages, students gradually shifted from intuitive or algorithmic responses toward more logical and evidence-based reasoning.

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GeoGebra played a critical role in strengthening this process by providing immediate visual feedback. When students manipulated geometric objects, incorrect assumptions or flawed reasoning became visually apparent. For example, when exploring geometric transformations, students could instantly observe whether the image of a point matched their predicted coordinates. This visual mismatch prompted students to reconsider their assumptions and revise their reasoning. As noted by Syahbana (2016), GeoGebra supports dynamic exploration and pattern observation, which are essential for developing conjectures and validating mathematical ideas. Thus, the improvement in reasoning was not solely due to the discovery steps or the software alone, but rather the synergy between both.

One of the most significant improvements was observed in the indicator of drawing conclusions and generalizing patterns. In Cycle I, students rarely formulated general rules and tended to rely on isolated examples. In Cycle II, after repeated exploration using GeoGebra, students were able to identify consistent patterns-such as transformation rules in rotations and dilations and articulate them symbolically. This finding supports Sumarmo's (2013) assertion that the ability to form conjectures and generalizations is a hallmark of advanced mathematical reasoning. GeoGebra enabled students to test multiple cases efficiently, thereby strengthening their confidence in drawing valid conclusions.

Furthermore, the group discussion component of discovery learning contributed to improvements in the indicator of examining the validity of arguments. Through peer interaction, students were encouraged to justify their solutions and respond to alternative viewpoints. This reflective dialogue aligns with Kadarisma's (2019) view that mathematical reasoning involves compiling evidence, evaluating arguments, and drawing conclusions based on logical inference. The visual representations provided by GeoGebra served as a common reference point during discussions, making abstract arguments more concrete and easier to evaluate.

In addition, the increased motivation and engagement observed during learning activities played a supporting role in enhancing reasoning ability. Visualization using GeoGebra made transformation geometry more interactive and accessible, consistent with Wulandari's (2020) findings that technology-based visualization improves students' interest and understanding. As students became more engaged, they were more willing to explore, question results, and refine their reasoning.

Overall, the findings indicate that the improvement in students' mathematical reasoning ability was driven by the cognitive structure of the discovery learning model, which systematically guided students through reasoning processes, and the dynamic visualization and feedback provided by GeoGebra, which supported conjecture formation, verification, and generalization. This study reinforces the theoretical perspective presented in the Introduction that mathematical reasoning develops most effectively when students are actively involved in structured discovery supported by appropriate technological tools.

CONCLUSIONS AND RECOMMENDATION

This study demonstrates that the effectiveness of GeoGebra-assisted discovery learning in improving students' mathematical reasoning lies in the synergy between structured discovery processes and dynamic visualization. Rather than merely increasing test scores, this learning model supports the development of core reasoning skills, such as forming conjectures, verifying arguments, and drawing general conclusions based on visual and logical evidence. The improvement observed from Cycle I to Cycle II indicates that students' reasoning processes became more systematic, reflective, and logically grounded through repeated engagement in exploration and verification activities.

From a practical perspective, this learning model is particularly suitable for geometry transformation topics that involve changes in position, orientation, and size, such as translation, reflection, rotation, and dilation. These topics benefit greatly from dynamic manipulation and real-time feedback, which enable students to observe invariant properties and identify transformation patterns more effectively. Therefore, the use of GeoGebra-assisted discovery learning is especially recommended for instructional units that emphasize visualization, pattern recognition, and generalization.

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To ensure successful implementation, several technical and pedagogical prerequisites should be considered. Teachers are advised to prepare structured worksheets that guide students in making assumptions, recording observations, and justifying conclusions. Adequate access to computers or tablets and basic student familiarity with GeoGebra operations are also essential to prevent technical difficulties from hindering the reasoning process. In addition, classroom management strategies that support collaborative discussion are necessary to maximize the benefits of peer argumentation and reflection.

Future research may extend this approach to other mathematical topics that require high-level reasoning, such as function transformations or three-dimensional geometry, or explore its impact on other higher-order thinking skills beyond mathematical reasoning. Overall, the GeoGebra-assisted discovery learning model offers a practical and theoretically grounded instructional alternative for fostering meaningful mathematical reasoning in technology-enhanced learning environments.

Credit authorship contribution statement

RWZ: Resources, Project Administration, Methodology. YM: Methodology, Formal Analysis, Data Curation, Conceptualization.

Ethical declaration

All participants provided informed consent prior to their involvement in the study. They were informed about the study's purpose, procedures, and their right to withdraw at any time without consequence.

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Volume 10 Nomor 2 March 2026 | ISSN Cetak : 2580 - 8435 | ISSN Online : 2614 - 1337
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