

Utilization of GeoGebra in Mathematics Learning to Support Conceptual Understanding

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ABSTRACT

Conceptual understanding is a fundamental ability in mathematics learning because it provides the basis for students to connect various mathematical ideas, explain relationships between concepts, select appropriate procedures, and apply knowledge in different situations. The abstract nature of mathematics often causes difficulties when concepts are presented through symbols, formulas, and static images. The development of digital technology provides opportunities to create more interactive learning through GeoGebra as dynamic mathematics software. This study aims to analyze the use of GeoGebra in mathematics learning and identify its contribution to conceptual understanding based on previous studies. The study employs a library research method by reviewing relevant journal articles, books, conference proceedings, and academic sources. The data were analyzed through the stages of identification, selection, classification, interpretation, and synthesis. The results of the review indicate that GeoGebra is utilized to visualize concepts, manipulate objects, connect various representations, conduct mathematical explorations, and support problem-solving. These applications help students observe mathematical relationships, identify patterns, test conjectures, and develop conceptual understanding. The effectiveness of GeoGebra is influenced by learning design, teacher competence, student readiness, the characteristics of the learning material, and the availability of facilities. Thus, GeoGebra has the potential to support interactive, exploratory, and conceptually oriented mathematics learning.

Keywords: Conceptual Understanding, Digital Technology GeoGebra, Mathematics Learning, Mathematical Visualization

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INTRODUCTION

Mathematics is one of the fields of learning that holds an important position in the education system because it plays a role in developing logical, critical, systematic, analytical, and problem-solving skills (Cotič et al., 2024). Mathematics learning is not solely aimed at enabling students to perform arithmetic operations or obtain correct answers, but also at developing their ability to understand the meaning behind the symbols and procedures they use. Conceptual understanding serves as a foundation for students to build mathematical knowledge continuously. When a concept is well understood, students will find it easier to connect it with other concepts, use appropriate strategies, and apply their knowledge to various problems. Conceptual understanding holds a very important position because most mathematical knowledge is structured hierarchically. Concepts learned at one stage often serve as prerequisites for understanding subsequent concepts (Goldin, 2020). For example, understanding variables and relationships between variables provides a foundation for understanding functions, while an understanding of functions can be used to study more complex topics such as equations, graphs, calculus, and mathematical modeling. This condition indicates that difficulties in understanding basic concepts can have a continuing impact on subsequent learning processes. Therefore, mathematics learning needs to pay sufficient attention to the process of developing conceptual understanding, rather than focusing solely on final outcomes.

In practice, understanding mathematical concepts remains a challenge for many students. One of the contributing factors is the abstract nature of mathematics, which involves numerous abstract objects and uses a symbolic system that is not always easy to understand. Students may know certain formulas and even be able to apply them to routine problems, but this does not necessarily mean that they understand why the formulas are used or the relationships between the formulas and other representations. This condition demonstrates a distinction between procedural mastery and conceptual understanding. Learning that places excessive emphasis on memorizing procedures may cause students to experience difficulties when dealing with problems presented in different contexts or forms. These difficulties become more apparent in mathematical topics that require visualization skills. Topics such as geometry, transformations, functions, graphs, coordinates, and calculus contain mathematical relationships that are often difficult to imagine through verbal explanations or static images. When students are exposed to only one form of representation, they may be able to memorize procedures but may not fully understand how changes in one element affect another. Therefore, learning media are needed that can provide a more dynamic learning experience, enabling students to observe, manipulate, and explore mathematical objects directly.

The development of digital technology provides opportunities to address some of these needs. Technology can be used to present various forms of representation, provide interactive learning experiences, facilitate exploration, and offer feedback during the learning process (Bresciani et al., 2022). In the context of mathematics education, the use of technology also enables students to perform activities that were previously difficult to carry out manually, such as dynamically manipulating graphs, changing parameters, conducting simulations, and directly observing mathematical relationships. One of the software applications widely used in mathematics education is GeoGebra. GeoGebra is dynamic mathematics software that integrates various areas

of mathematics, including geometry, algebra, graphing, statistics, and calculus (Gökçe & Güner, 2022). The strength of GeoGebra lies in its ability to connect multiple representations within a single environment. Changes to one object can be immediately observed in other representations, allowing students to examine the relationships among visual, symbolic, and numerical forms.

These dynamic characteristics provide opportunities for more exploratory mathematics learning. Students do not merely view completed images or graphs but can manipulate objects and observe the consequences of their actions. For example, in learning about functions, students can change parameter values and observe changes in the shape of graphs. In geometry, students can move points or change the size of an object and then observe which relationships remain constant or change. Such activities can help students discover mathematical patterns and relationships through direct experience. However, the use of GeoGebra does not automatically result in conceptual understanding. Technology is essentially only a tool, while the quality of learning depends largely on how the tool is utilized. If GeoGebra is used merely to display graphs or quickly generate images, its pedagogical benefits may be limited. Conversely, when GeoGebra is incorporated into activities that encourage students to make predictions, test conjectures, compare results, explain patterns, and draw conclusions, the technology can play a stronger role in developing conceptual understanding.

Therefore, there is a need to examine the use of GeoGebra not only from a technological perspective but also from a pedagogical perspective. The important question is not simply whether GeoGebra can be used in mathematics learning, but rather how the technology can be utilized to help students develop conceptual understanding. A review of previous studies is necessary to identify patterns in the use of GeoGebra, the types of activities conducted, the mathematical concepts being addressed, and the findings reported by previous research. A literature review is also important because research on GeoGebra has been conducted in various contexts, subject areas, educational levels, and instructional designs (Putri, 2024). This diversity has resulted in findings that are not always consistent. Some studies emphasize improvements in learning outcomes, while others focus on conceptual understanding, problem-solving skills, reasoning, visualization, or student engagement. Therefore, a synthesis is needed to obtain a more comprehensive picture of GeoGebra's contribution to mathematics learning. Based on the discussion above, this study aims to analyze the use of GeoGebra in mathematics learning based on a literature review, identify its forms of utilization in supporting conceptual understanding, analyze the mechanisms through which GeoGebra can facilitate the process of understanding, and identify the supporting factors and challenges that influence the successful implementation of GeoGebra in mathematics learning.

METHOD

This study employs the library research method, also known as a literature review. This method was chosen because the focus of the study is to examine, compare, and synthesize various published research findings concerning the use of GeoGebra in mathematics learning (Sarief et al., 2023; Sugiono, 2025). The study does not collect primary data through experiments, observations, or interviews; instead, it utilizes secondary data obtained from relevant scientific sources. The use of the library

research method enables the researchers to gain a broader understanding of the development of GeoGebra utilization. Through reviewing various sources, the researchers can identify trends in research findings across different contexts and compare how GeoGebra is used to achieve different learning objectives. Thus, the study does not focus solely on the findings of a single study but seeks to draw conclusions based on a synthesis of various findings. The data sources in this study consist of scientific literature related to GeoGebra and mathematics learning. The literature includes national and international journal articles, academic books, conference proceedings, research reports, and other scientific sources relevant to the focus of the study.

The literature was selected based on several criteria. First, the sources had to discuss the use of GeoGebra or dynamic mathematics software with direct relevance to GeoGebra. Second, the sources had to be related to the mathematics learning process. Third, the sources had to provide information concerning conceptual understanding, mathematical representations, exploration, problem-solving, or other mathematical abilities relevant to the objectives of the study. Data collection was conducted through a literature search using relevant keywords. Several keywords were used, including GeoGebra in mathematics education, GeoGebra and conceptual understanding, GeoGebra mathematics learning, dynamic mathematics software, GeoGebra and mathematical representation, as well as equivalent keywords in Indonesian. The literature obtained was then screened based on the relevance of the titles, abstracts, and full texts to the research focus. Relevant articles were examined thoroughly to obtain information regarding the research objectives, characteristics of GeoGebra use, topics taught, student activities, research findings, as well as supporting and inhibiting factors..

RESULT AND DISCUSSION

RESULT

The results of the literature review indicate that the use of GeoGebra in mathematics learning has developed from its use as a visualization tool into its use as a learning environment that supports mathematical exploration and investigation. In its simplest application, teachers utilize GeoGebra to display graphs, geometric figures, or mathematical forms that are difficult to illustrate manually (Sianturi & Angraini, 2026). This use provides advantages in terms of visual clarity and efficiency in presenting learning materials. At a more interactive level, GeoGebra is used to provide students with opportunities to manipulate mathematical objects. Students can change values, move points, zoom in or out of objects, and observe the resulting changes. Such activities provide a more active learning experience because students do not merely receive representations prepared by the teacher but can construct representations through their own actions. This development demonstrates a shift in the function of GeoGebra from merely being a presentation medium to becoming a tool for mathematical exploration. This change in function has important implications for conceptual learning. When students can manipulate objects and observe changes, they have opportunities to discover mathematical relationships based on direct experience. Visualization is one of the main benefits of GeoGebra frequently identified in the literature. This technology enables abstract mathematical concepts to be presented in visual and dynamic forms. Students can observe how a mathematical

object changes when certain conditions are modified. Visualization is important because mathematical understanding often requires the ability to connect symbolic representations with visual representations. For example, students learning about functions need not only to know the equation but also to understand how the equation is related to its graph.

With GeoGebra, these relationships can be displayed simultaneously. When a parameter in an equation is changed, the corresponding changes in the graph can be observed directly. This experience provides students with opportunities to understand the cause-and-effect relationships inherent in a concept (Syamil et al., 2026). However, visualization cannot stand alone. Students need to be guided to interpret what they observe. Without appropriate questions and reflective activities, visualization may become an experience that is visually engaging but does not lead to deep conceptual understanding. The literature review also indicates that GeoGebra plays an important role in connecting multiple mathematical representations. Mathematical concepts can be represented through graphs, symbols, tables, diagrams, or geometric forms. The ability to connect multiple representations is an important component of conceptual understanding because a mathematical concept does not have only one form of representation. Students who are able to move from symbolic representations to graphs, or from graphs to symbolic forms, demonstrate a more flexible understanding. GeoGebra facilitates this process because changes in one representation can be associated with changes in other representations. Students can see that an equation is not merely a collection of symbols but also has a graphical representation and specific mathematical relationships.

Tabel 1. Utilization of GeoGebra Based on Forms of Representation

Form of Representation	Example of Utilization	Expected Impact
Graphs	Observing changes in function graphs	Understanding relationships between variables
Algebra	Changing equation parameters	Connecting symbolic and visual representations
Geometry	Manipulating points and geometric figures	Understanding geometric properties and relationships
Tables	Observing changes in values	Identifying patterns
Animation	Observing processes of change	Understanding dynamic relationships
Measurement	Measuring length, angles, or area	Connecting concepts with objects

The use of GeoGebra enables students to explore mathematical concepts. Such exploration can be conducted through experimentation with various values or conditions. Students can observe what remains constant, what changes, and what patterns emerge. Exploratory activities provide students with opportunities to formulate conjectures. After identifying a particular pattern, students can test whether the pattern holds under other conditions. Thus, the learning process is not merely about receiving established concepts but also involves activities of discovering and

testing. In this context, GeoGebra can serve as a tool that helps students engage in mathematical activities resembling an investigative process. The technology accelerates the experimentation process, allowing students to explore more possibilities within a relatively limited amount of time (I. Al Ayyubi et al., 2025). The synthesis of the literature indicates that GeoGebra can support several aspects of conceptual understanding. First, GeoGebra helps students understand the characteristics of mathematical objects through manipulation and observation. Second, GeoGebra helps students connect concepts with various representations. Third, GeoGebra provides opportunities to discover patterns and relationships. Fourth, GeoGebra can be used to assess understanding through the application of concepts in particular situations. Conceptual understanding developed through exploration has a different character from understanding acquired solely through memorization. Students gain experience in how mathematical relationships are formed and why those relationships hold. However, it is important to emphasize that GeoGebra serves as a facilitator of this process. Understanding is ultimately developed through students' cognitive activities, such as observing, comparing, reasoning, generalizing, and communicating their findings.

GeoGebra can also be utilized in problem-based learning. When solving a problem, students can use graphs, geometric constructions, tables, or other representations to understand the given situation. The technology can help students test strategies more quickly (I. I. Al Ayyubi et al., 2024). If a conjecture produces an unexpected result, students can modify their strategies and conduct further testing. Nevertheless, the use of GeoGebra needs to be carefully controlled so that it does not diminish the thinking process. Students should not merely enter information into the application to obtain an answer. They need to explain how a strategy is applied and why the resulting answer is acceptable. The interactivity of GeoGebra provides opportunities to increase student engagement in learning. Students can directly interact with mathematical objects, making the learning process more active.

However, engagement does not simply mean that students are actively using a device. More importantly, engagement involves cognitive participation. Students need to use technology as a means of thinking, rather than merely as a tool for operating an application. Therefore, activity design plays a crucial role. Activities that ask students to formulate conjectures, identify patterns, provide explanations, and draw conclusions are more likely to generate cognitive engagement than activities that merely require students to follow steps for using the application. Teachers continue to play a central role in the use of GeoGebra. Although technical skills in operating the application are necessary, pedagogical skills are far more important. Teachers need to understand how GeoGebra can be used to achieve specific learning objectives. Teachers also need to design questions that can guide students from visual activities toward mathematical understanding. For example, teachers should not simply ask students to observe changes in a graph. Instead, they can ask students to explain why the graph changes, formulate conjectures about parameter relationships, and then test those conjectures. In this way, teachers act as designers of learning experiences and facilitators of students' thinking processes.

Although it offers considerable potential, the use of GeoGebra also has several limitations. One of the challenges is teacher competence (Syamil et al., 2026). Teachers who are not accustomed to using technology may experience difficulties in creating

constructions or designing appropriate learning activities. Another challenge is student readiness. Students who are unfamiliar with mathematical software may need time to learn its basic features. If not properly designed, instructional time may be spent more on learning how to use the application than on understanding mathematical concepts. Limited facilities are also a factor that needs to be considered. Not all learning environments have adequate devices or equal access to technology. Therefore, the use of GeoGebra needs to take into account the actual conditions of the learning environment. In addition, there is a risk of technological dependency. Students may become overly dependent on visual representations or application features and consequently become less accustomed to reasoning without technological assistance. Therefore, learning should combine the use of GeoGebra with manual activities, discussions, mathematical proofs, and mathematical explanations.

DISCUSSION

The findings indicate that one of GeoGebra's main contributions is its ability to bridge the abstract nature of mathematics with more concrete visual experiences. Mathematics uses symbols and relationships that often cannot be observed directly. GeoGebra enables these relationships to be displayed through manipulable objects. When students move points, change parameters, or modify objects, they can observe the mathematical consequences of their actions (I. I. Al Ayyubi, Rahmawati, et al., 2025). This experience can help establish connections between actions, visual changes, and mathematical concepts. However, these connections do not develop automatically. Teachers need to provide guidance so that students do not merely observe changes but also understand the meaning behind those changes. In other words, visualization needs to be followed by interpretation and reflection. The use of GeoGebra can support exploration-based learning by giving students opportunities to experiment, observe, and discover patterns. Such exploratory activities can provide more meaningful learning experiences because students are involved in the process of constructing knowledge (Siregar et al., 2023). Students not only learn that a particular formula or relationship is valid but also gain experience in understanding how that relationship can be discovered.

In mathematics learning, this process is particularly important because mathematics is not merely a collection of facts and formulas but also involves identifying patterns, making generalizations, and providing reasoning. The findings of the review indicate that the effectiveness of GeoGebra does not depend solely on its technological features. Advanced technology will not have a maximum impact if it is used without a clear pedagogical design. The use of GeoGebra should begin with clearly defined learning objectives (I. Al Ayyubi et al., 2025; I. I. Al Ayyubi, Rohaendi, et al., 2025). Once the objectives have been established, teachers can select appropriate features and activities. Thus, technology should follow the needs of learning rather than the other way around. This approach is important to prevent learning from becoming merely an activity of using an application. The focus should remain on conceptual understanding and mathematical thinking skills. The use of GeoGebra can encourage a shift in students' roles from information recipients to active participants in exploration. Students have opportunities to experiment and construct understanding based on their experiences. This shift can support more active learning.

However, student activities still require structure. Excessively open-ended exploration may cause students to lose direction and simply experiment with various features without understanding the learning objectives. Therefore, teachers need to provide appropriate boundaries and guiding questions. Such structure may take the form of worksheets, investigative questions, contextual problems, or tasks that require students to provide explanations for the results of their explorations.

Good conceptual understanding enables students to view a concept from various perspectives. GeoGebra can support this flexibility through the use of multiple representations (Birgin & Uzun Yazıcı, 2021). For example, students can begin with an equation, then observe its graph, examine its corresponding table of values, and connect it to a contextual situation. Moving between representations helps students understand that these different forms actually describe the same mathematical relationship. This flexibility is important when students encounter problems that are presented differently from the examples they have been given. They can use their conceptual understanding to determine the most appropriate representation. One important consideration is that the use of technology should not replace the reasoning process. GeoGebra can help students identify patterns, but an observed pattern does not necessarily constitute mathematical proof.

Students still need to learn to distinguish between observations and mathematical proof. GeoGebra can be used to formulate conjectures or develop intuition, but in certain contexts, students need to continue the process by providing mathematical arguments. Therefore, the use of GeoGebra should ideally serve as a starting point for developing mathematical reasoning. After identifying a pattern through exploration, students can be asked to explain why the pattern occurs and whether it can be generalized. The findings of the review have several implications for mathematics learning. GeoGebra can be used to strengthen the visualization of concepts that are difficult to understand through static media, provide students with opportunities to conduct exploration and investigation, connect multiple mathematical representations, support problem-based learning by providing tools for testing and evaluating strategies, and encourage mathematical discussion when the results of exploration are used as material for collective discussion (I. I. Al Ayyubi, Rahmawati, et al., 2025).

However, such implementation must be adapted to the characteristics of the mathematical content and the learning context. Not every mathematical concept requires digital technology. The use of technology should be based on pedagogical considerations regarding the added value it provides to the learning process. Based on the synthesis of the literature, the use of GeoGebra can be designed as an integrated sequence within the overall learning process. The teacher can begin by presenting a problem or situation related to the concept to be learned, followed by asking students to formulate conjectures based on their prior knowledge. Students then use GeoGebra to test their conjectures through manipulation and observation. Afterward, they analyze the results by recording changes, identifying patterns, and comparing findings. The learning process continues with discussion, in which students explain their findings and provide mathematical reasoning. The teacher then helps students connect the results of their exploration with formal mathematical concepts, definitions, or principles. Finally, students apply the concepts they have understood

to solve other problems. This model demonstrates that GeoGebra should not be positioned as a separate activity but rather integrated into the overall learning process.

CONCLUSION

Based on the results of the literature review, it can be concluded that GeoGebra has strong potential to support mathematics learning, particularly in helping students understand concepts that are abstract in nature and require multiple forms of representation. GeoGebra's ability to display mathematical objects dynamically enables students not only to observe a concept but also to manipulate and explore it. The use of GeoGebra can support conceptual understanding through several main mechanisms, namely visualization, manipulation, the connection of multiple representations, exploration, testing conjectures, problem-solving, and reflection. These activities provide students with opportunities to construct understanding based on their experiences and observations and then connect them with formal mathematical concepts. The findings also indicate that GeoGebra has greater pedagogical value when it is used in learning that positions students as active participants. Students do not merely follow procedures for operating the application but are guided to observe, formulate conjectures, test them, provide reasoning, and draw conclusions.

Thus, GeoGebra can function as a tool that supports mathematical thinking processes. Nevertheless, the use of GeoGebra cannot be separated from the role of the teacher. Teachers remain primarily responsible for determining learning objectives, selecting appropriate activities, providing guiding questions, helping students interpret the results of their explorations, and connecting digital experiences with formal mathematical concepts. Therefore, teachers' pedagogical and digital competencies are important factors in determining the success of GeoGebra implementation. In addition to teacher competence, the successful use of GeoGebra is also influenced by the characteristics of the learning material, student readiness, the availability of facilities, instructional time, and activity design. Poorly planned use of GeoGebra may cause students to focus more on operating the technology than on understanding mathematical concepts. Moreover, excessive use of technology may lead to dependency and reduce opportunities for students to develop independent reasoning skills.

Therefore, GeoGebra should be positioned not as the goal of learning but as a pedagogical tool that supports mathematical thinking and understanding. The use of GeoGebra needs to be accompanied by activities that guide students from visual experiences toward analysis, reasoning, communication, and generalization. Through this approach, technology not only makes mathematics learning more engaging but can also provide more meaningful learning experiences. Overall, this review demonstrates that the use of GeoGebra has considerable potential to support mathematics learning that is more interactive, exploratory, and oriented toward conceptual understanding. However, the success of its implementation is not determined solely by the sophistication of the technology. A harmonious integration of technology, pedagogy, mathematical content, and students' thinking activities is the key to ensuring that GeoGebra genuinely contributes to improving the quality of mathematics learning.

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