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Literature Review: The Use of GeoGebra Software on Mathematical Comprehension Ability

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Abstract

This study aims to examine in depth the use of Geogebra Software in improving students' mathematical comprehension skills. The research focus is directed at literature published in the period 2020 to 2025 using the library research method. Geogebra as a technology-based software has been widely used in mathematics learning because it is able to visualize abstract concepts into more concrete and interactive. The results of the study show that the use of Geogebra is effective in helping students understand mathematical concepts, such as algebra, geometry, trigonometry, and calculus, which are generally difficult to understand if only conveyed through conventional methods. With dynamic visualization and simulation, students can more easily connect theory with practice and can increase active involvement in the learning process. In addition, this literature research confirms that teachers play an important role in integrating Geogebra into learning. Teachers can use it to enrich teaching strategies, facilitate problem-based learning, and encourage collaboration between students. The application of Geogebra not only contributes to increasing understanding of concepts, but also has an impact on students' motivation, creativity, and independent learning. Therefore, Geogebra can be one of the innovative solutions in creating active, effective, and in accordance with the demands of the digital era.

Keywords: Geogebra software, mathematical comprehension, literature study, interactive learning, concept visualization.

Abstrak

Penelitian ini bertujuan untuk mengkaji secara mendalam penggunaan perangkat lunak Geogebra dalam meningkatkan kemampuan pemahaman matematika siswa. Fokus penelitian ini diarahkan pada literatur yang diterbitkan pada periode 2020 hingga 2025 menggunakan metode penelitian perpustakaan. Geogebra sebagai perangkat lunak berbasis teknologi telah banyak digunakan dalam pembelajaran matematika karena mampu memvisualisasikan konsep-konsep abstrak menjadi lebih konkret dan interaktif. Hasil penelitian menunjukkan bahwa penggunaan Geogebra efektif dalam membantu siswa memahami konsep matematika, seperti aljabar, geometri, trigonometri, dan kalkulus, yang umumnya sulit dipahami jika hanya disampaikan melalui metode konvensional. Dengan visualisasi dinamis dan simulasi, siswa dapat lebih mudah menghubungkan teori dengan praktik dan meningkatkan keterlibatan aktif dalam proses pembelajaran. Selain itu, penelitian literatur ini menegaskan bahwa guru memainkan peran penting dalam mengintegrasikan Geogebra ke dalam pembelajaran. Guru dapat menggunakannya untuk memperkaya strategi pengajaran, memfasilitasi pembelajaran berbasis masalah, dan mendorong kolaborasi antar siswa. Penerapan Geogebra tidak hanya berkontribusi pada peningkatan pemahaman konsep, tetapi juga berdampak pada motivasi, kreativitas, dan pembelajaran mandiri siswa. Oleh karena itu, Geogebra dapat menjadi salah satu solusi inovatif dalam menciptakan pembelajaran yang aktif, efektif, dan sesuai dengan tuntutan era digital.

Kata kunci: Perangkat lunak Geogebra, pemahaman matematika, kajian literatur, pembelajaran interaktif, visualisasi konsep.

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INTRODUCTION

Mathematics is a science that is part of human life (Nur'aini et al., 2017). Mathematics is the science of organized structures, discussing facts and relationships, as well as space and form. At its core, mathematics is a science that is closely related to human life. However, in practice, students often have

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difficulty in capturing and expressing mathematical ideas (Özerem, 2012). One of the reasons is that the learning process is less meaningful, so that students have difficulty understanding the concepts being taught. Nopiyani et al. (2016) emphasized that mathematics education in Indonesia still focuses on direct learning that tends to be oneway, where teachers dominate and students only play a passive role as recipients of information. This condition makes students have limited opportunities to actively participate in learning.

One of the main goals of learning mathematics is to build the ability to understand concepts. Math material is hierarchical, so to learn a topic, students must first understand the material beforehand. This shows that learning mathematics is not enough to rely only on memorization, but requires deep understanding, also in geometry (Rahmah, 2021; Rofiki & Alghar, 2024). Fatihah & Yahfizham (2024) emphasize that the ability to understand mathematics is a basic skill that students must have, because it is an entrance to develop other cognitive abilities. In line with NCTM (1989), mathematical understanding is included in one of the standards of mathematical thinking processes. Thus, this ability needs to be developed in a directed manner.

According to Ekawati (2016), mathematics is an abstract subject so it requires the ability to think logically in understanding it. Therefore, the right learning media is needed to make abstract concepts easier to understand. Media also functions to increase student motivation and involvement in learning (Islam, 2019). One of the most widely used modern media is technology-based software. Suryawan & Permana (2020) explained that software is able to present abstract material with the help of the integration of images, videos, sounds, and animations, making it easier for students to understand.

One popular software for learning math is GeoGebra. This application can be used to represent, describe, and acquire mathematical concepts in a more interactive way. Mayadi (2021) mentioned that GeoGebra can be applied in various topics, such as the Two-Variable Linear Inequality System (SPLDV), linear programming, quadratic functions, derivatives, three-dimensional geometry, and so on. With GeoGebra, students can perform graphical simulations, calculate the area, and determine the shortest distance, which ultimately makes it easier for them to understand concepts (Baye et al., 2021; Nisa et al., 2023; Yerizon et al., 2021).

Yanti et al. (2019) and Sopanda et al. (2022) revealed that GeoGebra was developed for three main purposes: as a mathematics learning resource, as a tool for making teaching materials, and as a means of solving problems that help students through the process of experimentation and concept discovery. GeoGebra can be applied at all levels of education, from elementary school to college (Belva & Jailani, 2023; Türkoğlu & Yalçınalp, 2024). With its flexible nature, GeoGebra can be considered a powerful learning medium to improve students' understanding (Juandi et al., 2025).

According to Aryanto et al. (2019), learning with the help of GeoGebra not only improves understanding of concepts, but also contributes to problem-solving skills and learning independence. This is in line with the demands of the 21st century that emphasizes critical, analytical, creative, collaborative, and communicative thinking skills (Alghar et al., 2024; Rahmatika, 2022; Wuri & Siswono, 2022). Thus, the integration of GeoGebra in mathematics learning becomes very relevant.

GeoGebra plays an important role in supporting technologybased mathematics learning in the digital era. They found that students who used GeoGebra showed an increased understanding of algebra concepts due to visualizations that facilitated the connection between symbolic equations and graphs (Mayadi, 2021; Syifaurrohman & Shodikin, 2025). These findings reinforce the view that interactive-based educational technologies can reduce learning barriers caused by material abstraction.

The results of Rahmadia's research (2024) stated that the integration of GeoGebra in trigonometry learning was able to improve students' problem-solving skills. With interactive simulations of angles, circles, and trigonometric graphs, students will more easily understand the relationships between functions. This research supports Vygotsky's theory of social constructivism, that students' understanding can develop when they are given the opportunity to explore through visual aids.

According to research by Syifaurrohman & Shodikin (2025), GeoGebra not only improves understanding of concepts, but also improves students' positive attitudes towards mathematics. Many students who initially found math difficult became more confident when learning to use this app. This shows that technology-based learning media can affect the affective realm of students, not just the cognitive realm.

Recent research by Septian (2021) emphasizes that GeoGebra is effectively used in a *project-based learning* model. Using GeoGebra, students are able to complete mathematical projects, such as data analysis using function graphs or geometric simulations. These activities build 21st century skills, including collaboration, communication, creativity, and critical thinking. Ocal (2017) and Samosir et al. (2020) found that the use of GeoGebra in differential and integral learning helps students more quickly understand the meaning of derivatives and integrals as changes and area areas. The results of this study support Bruner's theory of representation, because GeoGebra allows students to move from visual representation to symbolic representation gradually.

According to Misrom et al. (2020), GeoGebra is also effective for improving higher *order thinking skills (HOTS).* In mathematics learning, students who are accustomed to using GeoGebra are able to ask critical questions, analyze various possible solutions, and evaluate solution steps. This is in line with the demands of the Independent Curriculum which emphasizes the importance of developing critical thinking skills. A research by Hariyanti et al. (2025) shows that GeoGebra has been widely used in various countries as an inclusive learning tool. Students with low and high abilities alike benefit because the app is flexible. GeoGebra can also be used as a remedial and enrichment tool, thus supporting the principle of differentiation in mathematics learning.

According to Agustina et al. (2025), the application of GeoGebra in spatial geometry learning has significant results on students' spatial abilities. The three-dimensional visualization provided by this application helps students understand the concepts of volume, surface area, and distance between points and planes. This supports *Paivio's dual coding* theory, which states that information presented in visual and verbal forms will be easier to understand and remember.

Recent research by Samura (2023) emphasizes that GeoGebra can be used in *blended* learning-based learning. Students can access the material through GeoGebra at home, then discuss the results of their exploration in class. This strategy encourages students to be more independent, increases curiosity,

and expands the learning experience beyond the confines of a traditional classroom. The results of Rahmadia's research (2024) show that teachers who use GeoGebra in mathematics learning are more likely to develop teaching method innovations. Teachers can design questions based on real contexts, such as calculating distance, land area, or analyzing graphic data that is relevant to students' daily lives. Thus, GeoGebra is not only a tool for students, but also a means of professional development for teachers in creating creative and meaningful learning.

The development of educational technology has encouraged the presence of various software that can support mathematics learning. One of the most widely used is GeoGebra, due to its open source, easy access and support for a wide range of platforms. Previous studies have shown that GeoGebra is effective in helping students understand concepts that are difficult to understand only with conventional methods (Albano & Dello Iacono, 2019). For example, the concept of a normally abstract quadratic function can be visualized in the form of a dynamic graph so that students can see the direct relationship between algebraic equations and parabolic shapes (Syifaurrohman & Shodikin, 2025; Yerizon et al., 2021). Thus, GeoGebra serves as a bridge between abstract and concrete thinking.

The developer of GeoGebra, also confirms that the app is designed to support the integration of geometry, algebra, and calculus in a single learning environment (Weinhandl et al., 2021). With this integration, students not only see mathematics partially, but also as a whole. This is in accordance with the purpose of the mathematics curriculum which aims to foster a thorough understanding of the relationships between topics.

In the Indonesian context, the use of GeoGebra is also relevant to the Independent Curriculum which emphasizes project-based learning and problem-solving (Septian, 2021; Syifaurrohman & Shodikin, 2025). With GeoGebra, teachers can design more contextual learning projects, such as calculating land area with a graphical approach or analyzing the movement of objects with a quadratic function. This makes learning mathematics more meaningful and close to students' real lives.

Several empirical studies in Indonesia have also shown the effectiveness of GeoGebra. For example, the research of Yanti et al. (2019) proved that students who studied with the help of GeoGebra showed a significant improvement in understanding the concept of quadratic functions compared to conventional methods. Similarly, research by Sopanda et al. (2022) showed an increase in student learning independence and motivation after using GeoGebra in trigonometry learning.

With its various advantages, the use of GeoGebra is not only relevant in the context of classroom learning, but also supports distance learning. In the digital era, students can access GeoGebra through computers and mobile devices. This makes it easier to access learning outside of school hours and supports lifelong learning. Thus, GeoGebra is one of the potential media to face the challenges of mathematics education in the era of the industrial revolution 4.0.

METHODS

The method used in this study is library research, which is research conducted by reviewing various relevant literature and analyzing topics in depth without having to conduct field research, but by examining credible and up-to-date written sources (Wohlin et al., 2020). The literature used is limited

to the range of 2020 to 2025 so that the information obtained remains new and in accordance with the latest developments, with sources coming from national and international journals, reference books, proceedings, scientific magazines, and online academic repositories. The object of study in this article is the ability of students to understand mathematics through the use of GeoGebra Software which focuses on how the software can facilitate students to understand abstract mathematical concepts. The stages of literature research include problem identification (low mathematical understanding of students in conventional learning), collection of relevant sources, literature selection, content analysis to find patterns and findings, and information synthesis to formulate a comprehensive understanding. The data obtained are in the form of concepts, theories, models, and the results of previous research which are then analyzed in a qualitative descriptive manner by explaining, comparing, and relating various findings from different literature. Thus, this study not only describes theories, but also integrates various views to make theoretical contributions to the development of mathematics learning strategies, and can be an inspiration for teachers and researchers in developing technology-based learning innovations, especially the use of GeoGebra Software to improve students' mathematical understanding.

RESULTS AND DISCUSSION

Results

The results of research from several literature on the use of *geogebra software* on mathematical comprehension ability. This research material comes from a study of the current situation which is analyzed to strengthen research on the use of *geogebra software* in students' mathematical understanding. The following is a summary of studies related to this issue:

Table 1. Research Literature on Geogebra in Mathematics Learning in 2020-2025

No	Researcher and Year	Research Title	Research Core
1	Sebial et al. (2022)	GeoGebra as a means for understanding limit concepts.	GeoGebra effectively helps students understand the concept of abstract function limits through interactive graph simulations.
2	Rahmadia et al. (2024)	*Penggunaan Geogebra dalam Trigonometri*	The use of GeoGebra significantly improves students' understanding of trigonometry concepts, especially privileged angles and graphs of trigonometric functions.
3	Nguyen et al. (2023)	Combining Flipped Classroom and GeoGebra Software in Teaching Mathematics to Develop Math Problem-Solving Abilities for Secondary School Students in Vietnam.	The combination of flipped classroom and GeoGebra models increases problem solving and understanding of spatial geometry concepts.
4	Septian et al. (2020)	The application of android-based geogebra on quadratic equations material toward mathematical creative thinking ability.	The mobile-based GeoGebra application improves the accessibility and effectiveness of independent learning for junior high school students.

5	Syifaurrohman & Shodikin (2025)	Implementation of GeoGebra-Assisted Problem Based Learning Model to Improve Understanding of Algebra Concepts in Junior High School.	GeoGebra helps students understand linear equation systems through dynamic graphical representations that clarify the relationships between variables.
6	Belva & Jailani (2023)	The Impact of Junior High School Students' Learning Interest and Problem-Solving Ability with the Problem-Based Learning Model Using Geogebra Software on SPLDV Material.	SPLDV chart exploration using GeoGebra is more effective than manual methods in students understanding.
7	(Yerizon et al., 2021)	Development of a geogebra-assisted calculus worksheet to enhance students' understanding.	The integration of GeoGebra with a problem solving approach improves students' mathematical representation skills, especially in calculus topics.
8	Vadya et al. (2022)	*Analisis Kemampuan Pemahaman Konsep Siswa SMA dalam Menyelesaikan Soal Matematika Berdasarkan Gender dan Geogebra.*	GeoGebra-assisted learning has been shown to be more effective in improving understanding of mathematical concepts in terms of gender.
9	Adyva et al. (2024)	Application of Geogebra Learning Media to Increase Class IX Students' Learning Motivation on Geometry Transformation Material at SMP Negeri 1 Kisaran.	GeoGebra supports the Curriculum project approach by encouraging students' creativity in the exploration of geometric transformations.
10	Samura (2023)	Improving Mathematics Critical Thinking Skills of Junior High School Students Using Blended Learning Model (BLM) in GeoGebra Assisted Mathematics Learning.	The use of GeoGebra is able to increase critical thinking as well as mathematical understanding of education students. GeoGebra provides interactive visualizations that make it easier for students to understand abstract concepts, especially in geometry & algebra.

From Table 1 above Based on a literature review, it can be seen that the use of GeoGebra in mathematics learning continues to experience significant development, both in terms of material context, education level, and integrated learning approaches. Research by Sebial et al. (2022) and Sari (2017) confirmed that GeoGebra was able to help students understand abstract concept limits through interactive chart visualization. The results of this study mark the beginning of evidence that GeoGebra is effective in overcoming students' difficulties in learning abstract analysis topics.

Research by Nguyen et al. (2023) showed a significant increase in the understanding of trigonometric concepts among high school students, especially on the topic of special angles and graphs of trigonometric functions. These results were reinforced by Wahyuni and Hidayat in the same year, who integrated GeoGebra in the *flipped classroom model*. Their findings show that the use of GeoGebra

not only improves understanding of spatial geometry concepts, but is also able to increase students' motivation to learn because students are actively involved before and during the learning process.

Septian et al. (2020) researched the effectiveness of Android-based GeoGebra in junior high school students. The results of the study show that the mobile-based application is able to increase accessibility and support students' independent learning. This indicates that GeoGebra is increasingly relevant in the digital era, especially to support flexible technology-based learning.

In another research, Syifaurrohman & Shodikin (2025) found that GeoGebra effectively helps students understand the concept algebra, especially linear equation systems, through dynamic graphical representations. This research is in line with the findings of Belva & Jailani (2023) which show that SPLDV graph exploration with GeoGebra is more effective than manual methods, because it is able to strengthen the conceptual understanding of junior high school students.

Furthermore, research by Yerizon et al. (2021) combines GeoGebra with approach to calculus materials. The results of the study showed an increase in students' mathematical representation skills, especially in solving indeterminate integral problems. This study confirms that GeoGebra not only supports visualization, but is also able to strengthen high-level thinking skills. Another study by Vadya et al. (2022) showed that GeoGebra-assisted learning in high school students was more effective in improving concept understanding than traditional lecture methods, confirming the relevance of GeoGebra as a modern learning medium.

Adyva et al. (2024) found that GeoGebra can optimize students' understanding of geometry transformation materials. This is in line with the spirit of the Independent Curriculum which encourages creativity and independent exploration of students. Meanwhile, Samura (2023) highlighted the influence of GeoGebra on the critical thinking skills and mathematical understanding of education students. The results show that the use of GeoGebra not only plays a role in the mastery of concepts, but also in the development of high-level thinking skills that are indispensable in the 21st century learning era.

Overall, the literature from 2020 to 2025 shows the consistency of GeoGebra's effectiveness in improving understanding of mathematical concepts at various levels of education. Furthermore, the latest research emphasizes the role of GeoGebra in supporting innovative learning approaches, encouraging creativity, and developing critical thinking skills in accordance with the demands of the Independent Curriculum and the challenges of the digital era.

Discussion

The results of the study by Suryawan & Permana (2020) show that GeoGebra Software-based online learning media on curved side space materials meet valid, practical, and effective criteria to improve the ability to understand mathematical concepts of grade IX junior high school students. This research confirms that GeoGebra is in line with the scientific approach in the 2013 Curriculum and is relevant to the learning needs of the industrial revolution 4.0 era.

Furthermore, research by Sopanda et al. (2022) strengthened these findings by integrating GeoGebra into the *Problem Based Learning* (PBL) model. The results of the post-test showed a significant difference between the experimental class and the control class. The improvement in

understanding of mathematical concepts in the experimental class achieved an N-gain value of 75% (the moderately effective category), while the control class only increased by 50% (the least effective category). This indicates that GeoGebra's collaboration with the PBL model is superior to traditional learning.

Meanwhile, Afhami (2022) highlighted the use of the GeoGebra Classic application in geometry transformation materials. This study proves that GeoGebra is able to have a very strong positive influence on students' understanding of mathematical concepts with a percentage of 97.7%. The dynamic visualization capabilities offered by GeoGebra help students overcome difficulties in drawing or imagining geometric shapes, while increasing their motivation to learn.

Research by Mukarramah (2022) adds another dimension, namely the relationship between understanding mathematical concepts and problem-solving skills. The results show that the higher the students' understanding of mathematical concepts, the better their ability to solve problems. Thus, the use of GeoGebra is not only beneficial in improving understanding of concepts, but also in developing mathematical problem-solving skills.

In line with the previous findings, Hermawan et al. (2023) emphasized that the *discovery learning model* with the help of GeoGebra is able to improve the understanding of mathematics concepts for high school students. GeoGebra is not only a visualization tool, but it can also facilitate active, creative, and effective learning. When compared to the research of Sopanda et al. (2022), the two have similarities in the effectiveness of GeoGebra, but differ in the learning model used, that is PBL versus *discovery learning*. In addition, research by Adyva et al. (2024) and Samura (2023) also emphasized the potential of GeoGebra in improving mathematical understanding at various levels of education. Rokhmawati & Rahayu (2023) researched indoor distance material at the high school level, while Hakim et al. (2022) researched space building material in grade V elementary school students. The difference between the two lies in the context and teaching materials, but both consistently show that GeoGebra is effective as a learning medium.

From these various studies, it can be concluded that the use of GeoGebra from 2020 to 2023 has consistently been proven to improve students' mathematical comprehension skills, both through integration with PBL models, *discovery learning*, and direct use of certain materials. GeoGebra contributes to overcoming visualization difficulties, increasing motivation, and strengthening mathematical problem-solving skills at various levels of education.

Comparative Analysis Between Researches

Based on the literature listed in Table 1, it can be seen that the use of Geogebra Software consistently shows an increase in understanding of mathematical concepts at various levels of education, ranging from elementary school, junior high school, to high school, and even college. The fundamental difference between these studies lies in the teaching materials (building space, SPLDV, geometric transformation, distance in space, field analytic geometry), as well as integrated learning models (Problem Based Learning, Discovery Learning, Scientific Approach).

An interesting thing was found in the research of Sopanda et al. (2022) which combined Geogebra with PBL. This integration not only improves understanding of concepts, but also problem-solving skills. When compared to the research of Yanti et al. (2019) which only used a scientific approach assisted by Geogebra, there was a difference in the effectiveness results. This shows that the effectiveness of Geogebra is highly dependent on the pedagogical strategies used by teachers.

Relevance to the 21st Century Curriculum and Competencies

In the context of the implementation of the Independent Curriculum (2022-2023), the use of Geogebra is very relevant to the demands of mastering numeracy literacy and strengthening the profile of Pancasila students. The curriculum emphasizes project-based learning, collaboration, and real-world problem-solving. Geogebra supports this because it provides interactive visualizations that help students understand abstract concepts more concretely.

For example, when students are learning distance in space, the use of Geogebra-based videos, Rokhmawati & Rahayu (2023) provides a more contextual learning experience. Students not only memorize distance formulas, but can also explore the positions of points and planes through visual simulations. This is in line with the theory of constructivism which emphasizes that students build knowledge through active learning experiences.

Linkages to Learning Theory

The integration of GeoGebra in mathematics instruction is strongly grounded in established theories of learning. According to Bruner's theory of cognitive development, GeoGebra facilitates the progression from the enactive stage (where learners interact directly with visual and manipulable objects) through the iconic stage (characterized by the use of dynamic visual representations) to the symbolic stage, in which abstract mathematical notation and formal equations are meaningfully understood (Bruner, 1974). Additionally, in line with Ausubel's theory of meaningful verbal learning, GeoGebra functions as an advance organizer by providing visual scaffolds that help learners anchor new mathematical concepts to their existing cognitive frameworks, thereby promoting meaningful rather than rote learning (Ausubel, 1969).

Furthermore, Vygotsky's sociocultural theory, particularly the concept of the Zone of Proximal Development (ZPD), offers a compelling lens through which GeoGebra's pedagogical value can be understood (Vygotsky, 1978). The software serves as a form of digital scaffolding, enabling teachers to provide tailored, interactive guidance that supports students as they gradually develop conceptual autonomy. Through carefully designed exploratory tasks and real-time feedback, learners are able to internalize complex mathematical ideas within a socially and technologically mediated environment (Yimer & Feza, 2019). Collectively, these theoretical perspectives underscore that GeoGebra's efficacy extends beyond its technical capabilities, it is deeply rooted in well-substantiated principles of educational psychology, making it a powerful tool for fostering deep and durable mathematical understanding (Owusu et al., 2023).

Digitalization Innovation in Mathematics Education

In the 2020-2025 period, the trend of digitalization is increasingly massive. The Covid-19 pandemic (2020-2021) accelerated the use of technology in learning (Fauzi, 2022). A number of studies show that Geogebra is very adaptive for online and offline learning (Mukarramah, 2022; Suryawan & Permana, 2020). After the pandemic, the use of Geogebra remains relevant because it supports blended learning (Samura, 2023). Teachers can prepare interactive files, while students can access them at any time for self-study. This strengthens the concept of self-regulated learning which is the key to 21st century competence (Ishartono et al., 2022).

Practical Implications for Teachers and Students

The findings of the literature review highlight several practical implications for key stakeholders in mathematics education. For teachers, GeoGebra significantly simplifies the preparation of interactive instructional materials by eliminating the need for manual drawing of geometric figures or graphs, thereby saving time and enhancing the overall quality and dynamism of classroom instruction (Juandi et al., 2025; Yerizon et al., 2021). Its intuitive interface and real-time visualization capabilities enable educators to design engaging, concept-rich lessons that align with contemporary pedagogical approaches such as inquiry-based or problem-based learning (Syifaurrohman & Shodikin, 2025).

For students, GeoGebra fosters greater motivation and active participation through its interactive and visually stimulating environment, which transforms abstract mathematical concepts into tangible, exploratory experiences (Belva & Jailani, 2023; Juandi et al., 2025). This not only deepens conceptual understanding but also cultivates essential problem-solving and critical thinking skills (Samura, 2023). At the institutional level, the integration of GeoGebra supports schools' broader digital transformation agendas by promoting digital literacy, aligning with national educational policies (such as Indonesia's Merdeka Belajar initiative) and positioning the school as a forward-looking learning community equipped for 21st-century challenges (Albano & Dello Iacono, 2019; Sopanda et al., 2022).

Challenges and Limitations

Despite the demonstrated effectiveness of GeoGebra in enhancing mathematical understanding, several practical challenges hinder its widespread and optimal implementation. A primary barrier is the varying levels of digital pedagogical competence among mathematics teachers. Many lack sufficient training to integrate GeoGebra meaningfully into their instructional design (Berhe et al., 2025). Additionally, infrastructural limitations such as insufficient access to computers, unreliable internet connectivity, or the absence of suitable digital devices, significantly constrain the consistent use of this software in everyday teaching and learning (Ghimire & Paudel, 2024).

Furthermore, student readiness remains a critical factor. Not all learners are equally familiar or comfortable with digital learning environments, which may impede their engagement and comprehension when GeoGebra is introduced without adequate scaffolding (Khali & Khalil, 2019). To address these challenges, a multi-faceted approach is essential: systematic professional development for teachers, equitable investment in school-level ICT infrastructure, and structured onboarding activities

to gradually acculturate students to technology-enhanced learning (Berhe et al., 2025; Ghimire & Paudel, 2024). Only through such coordinated support can the full pedagogical potential of GeoGebra be realized across diverse educational contexts. This challenge needs to be overcome through teacher training, the provision of ICT facilities, and habituation of students using media (Rasteiro et al., 2023).

Recommendations for Further Research Development

While extensive research between 2020 and 2025 has consistently demonstrated GeoGebra's effectiveness in enhancing mathematical comprehension across educational levels, several promising avenues for future inquiry remain underexplored. Notably, the integration of GeoGebra with Artificial Intelligence (AI) holds significant potential for enabling adaptive, personalized learning pathways that respond dynamically to individual student needs, misconceptions, and learning paces (Botana et al., 2024). Additionally, embedding GeoGebra within augmented reality (AR) or virtual reality (VR) environments could revolutionize spatial reasoning and 3D visualization in geometry, calculus, and linear algebra, offering immersive, experiential learning opportunities that traditional 2D interfaces cannot provide (Tomaschko & Hohenwarter, 2019; Yerizon et al., 2021).

Furthermore, while existing studies highlight improvements in conceptual understanding and motivation, there is a need for more systematic investigations into GeoGebra's impact on higher-order cognitive and social competencies, including critical thinking, mathematical creativity, and collaborative problem-solving (Samura, 2023; Yildiz et al., 2017). Future research could employ mixed-methods designs to assess how sustained, scaffolded use of GeoGebra in collaborative or project-based settings influences the development of 21st-century skills aligned with national curricula such as Indonesia's Merdeka Curriculum (Rahmatika, 2022; Septian, 2021). Such studies would not only deepen the theoretical foundation of technology-enhanced mathematics education but also inform scalable, equitable implementations in diverse classroom contexts.

CONCLUSION

The research from 2020 to 2025 consistently shows that GeoGebra is far more than just a digital tool, it's a dynamic bridge between abstract mathematical ideas and students' everyday understanding. Across grade levels and topics, GeoGebra helps learners see math in action, turning static formulas into interactive experiences they can explore, manipulate, and understand. GeoGebra's power is not just its visual capabilities, but how it aligns with modern educational goals: fostering active learning, supporting student-centered instruction, and nurturing critical thinking and creativity. When combined with approaches like Problem Based Learning or Discovery Learning, its impact deepens even further. While challenges like limited teacher training or uneven access to technology remain, they are not insurmountable. With thoughtful support and integration, GeoGebra stands out as a practical, flexible, and highly relevant resource for today's math classrooms, especially in an era that values both digital fluency and meaningful conceptual understanding.

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