

## A Systematic Literature Review on the Effectiveness of GeoGebra in Mathematics Education in the Digital Era

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Article Info	ABSTRACT
<p><b>Keywords:</b> GeoGebra; Mathematics Education; Digital Learning; Conceptual Understanding; Student Engagement; Technology Integration; Systematic Review</p>	<p>The integration of digital technologies in mathematics education has become increasingly essential in the digital era. GeoGebra, an interactive mathematics software that combines algebra, geometry, calculus, and statistics, has been widely used to support visual and student-centered learning. This study aims to systematically review the literature on the effectiveness of GeoGebra in mathematics education by analyzing ten peer-reviewed articles published between 2020 and 2025. Using a qualitative descriptive design and systematic literature review method, the selected studies were examined in terms of their educational level, research design, and key findings. The results indicate that GeoGebra significantly enhances students' conceptual understanding, visualization skills, problem-solving ability, and critical thinking. Moreover, it fosters greater engagement and motivation, particularly when integrated into interactive or constructivist learning settings. However, the review also identified challenges, including teacher readiness, technological infrastructure limitations, and a lack of focus on long-term and non-cognitive outcomes. These findings highlight the need for professional development, pedagogical alignment, and institutional support to optimize GeoGebra's impact. Overall, GeoGebra holds strong potential as a transformative tool in mathematics instruction, provided its implementation is contextually and pedagogically supported.</p>
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### INTRODUCTION

The advancement of digital technology has fundamentally shifted paradigms in the education sector, including in mathematics learning, which is traditionally characterized by abstract reasoning and symbolic manipulation. In today's digital era, teacher-centered instruction is increasingly inadequate in addressing the learning needs of students who are more familiar with visual interactions and digital tools. As a result, teachers are expected not only to deliver content but also to act as facilitators capable of integrating technology into mathematics instruction to make learning more meaningful and relevant (Astuti & Zulfikar, 2021; Andreas et al., 2021).

One of the most widely used digital platforms in mathematics education is GeoGebra, an interactive application that combines algebra, geometry, calculus, and statistics into a single dynamic platform. GeoGebra enables both students and teachers to visualize abstract concepts in real-time and explore mathematical relationships actively. This aligns with the constructivist learning theory, which posits that students build knowledge through active engagement and interaction with their learning environment (Ramadhan, Rahmawati, & Arifin, 2021). GeoGebra has been proven to facilitate conceptual understanding, improve mathematical representations, and enhance procedural fluency (Putri & Subanji, 2022).

In the context of Indonesia's Kurikulum Merdeka, which promotes differentiated, exploratory, and collaborative learning, GeoGebra becomes highly relevant. Its features support the development of critical thinking, problem-solving skills, and creativity—key competencies in 21st-century education. Previous research has shown that the use of GeoGebra positively influences students' understanding of concepts, engagement, and mathematical attitudes (Wijayanti & Permana, 2023; Rachmadtullah et al., 2022).

Despite these advantages, the implementation of GeoGebra is not without challenges. Issues such as limited infrastructure, low digital literacy among students, and the lack of teacher training in using the software remain significant barriers, particularly in underdeveloped and remote areas (Herlina, 2021; Kurniawan & Setyowati, 2020). Furthermore, while numerous studies report the benefits of GeoGebra, most are isolated, small-scale, and focused on specific topics or grade levels.

More importantly, there is still a lack of comprehensive and systematic literature reviews that integrate findings from recent studies on the effectiveness of GeoGebra across different educational contexts. Few studies have examined its alignment with national education policies, especially in the post-pandemic era, where digital transformation is essential to ensure resilient and sustainable learning models (Yulianti & Harahap, 2021).

Another important gap is the limited discussion on non-cognitive aspects, such as students' emotional involvement, classroom interactions, and long-term teacher readiness in adopting GeoGebra. Research by Irvan and Mushlihuddin (2020) emphasized that integrating GeoGebra into classroom teaching requires ongoing teacher support and targeted professional development. In another study, Irvan et al. (2025) highlighted the potential of digital mathematics media such as GeoGebra and mathematical comics to foster student interest and engagement in learning through digital storytelling and visualization tools.

Therefore, a systematic review of current literature is urgently needed to: 1) Map out key findings on the effectiveness of GeoGebra in mathematics education; 2) Identify enabling and inhibiting factors; 3) Explore its role within the framework of Indonesia's evolving education system and digital curriculum policies.

This review aims to fill the aforementioned gaps by providing a comprehensive and contextual analysis of recent studies (2020–2025) on GeoGebra. The results are expected to serve as a foundation for instructional planning, teacher training initiatives, and the strategic development of digital learning resources based on GeoGebra in Indonesian schools.

## **RESEARCH METHOD**

This study adopts a systematic literature review approach to investigate the effectiveness of GeoGebra in mathematics education within the context of the digital era. The review was designed using a qualitative descriptive methodology, aiming to collect, evaluate, and synthesize existing empirical evidence from scholarly articles published between 2020 and 2025.

Relevant data sources included Google Scholar, ERIC, and ScienceDirect, where searches were conducted using keyword combinations such as "GeoGebra," "mathematics education," "interactive learning," "digital tools in teaching," and "technology integration in education." These keywords were selected to ensure the retrieval of studies that addressed both the pedagogical application of GeoGebra and its role in facilitating digital mathematics instruction.

To maintain rigor in article selection, a set of inclusion criteria was applied:

- a) articles must have been published between 2020 and 2025,
- b) written in English or Indonesian,
- c) focused on GeoGebra as a learning tool in mathematics education,
- d) contained empirical data (quantitative, qualitative, or mixed-methods), and
- e) published in reputable, peer-reviewed journals (preferably indexed in SINTA 2–3 or Scopus Q3–Q4).

An initial search yielded over 50 articles. After title and abstract screening, 30 articles were shortlisted for full-text analysis. Following a critical appraisal using a modified version of the CASP (Critical Appraisal Skills Programme) checklist, a final sample of 10 core studies was selected based on methodological clarity, topical relevance, and contribution to the research objectives.

Each of these selected studies was subjected to thematic content analysis. The analysis focused on several key dimensions:

- (1) the impact of GeoGebra on students' conceptual understanding,
- (2) improvements in problem-solving skills,
- (3) development of visualization and representation abilities,
- (4) influence on non-cognitive outcomes such as motivation and engagement, and
- (5) implementation factors including teacher readiness and technological infrastructure.

The findings were then synthesized to identify emerging patterns and thematic trends. In addition, graphical and tabular representations were developed to visually convey the frequency of outcomes and the methodological characteristics of the reviewed studies. Although this study does not involve human participants, academic ethics were maintained through proper citation, transparency of procedures, and adherence to scholarly review standards.

Through this method, the research seeks to provide a comprehensive, evidence-based understanding of how GeoGebra has been implemented in mathematics classrooms, what outcomes have been documented, and what challenges persist in ensuring its effective and sustainable use in the digital learning landscape.

## RESULTS AND DISCUSSION

### Results

This systematic literature review incorporated ten peer-reviewed articles published between 2020 and 2025 that investigated the effectiveness of GeoGebra in mathematics education across multiple educational levels. The studies utilized various research designs, including experimental, quasi-experimental, survey-based, qualitative, and developmental approaches.

To provide a clearer overview of the studies analyzed, Table 1 below summarizes key information from each article, including the authorship, targeted education level, research design, and main findings. This table serves as a comparative reference that highlights the diversity of contexts in which GeoGebra was applied and the outcomes that were observed.

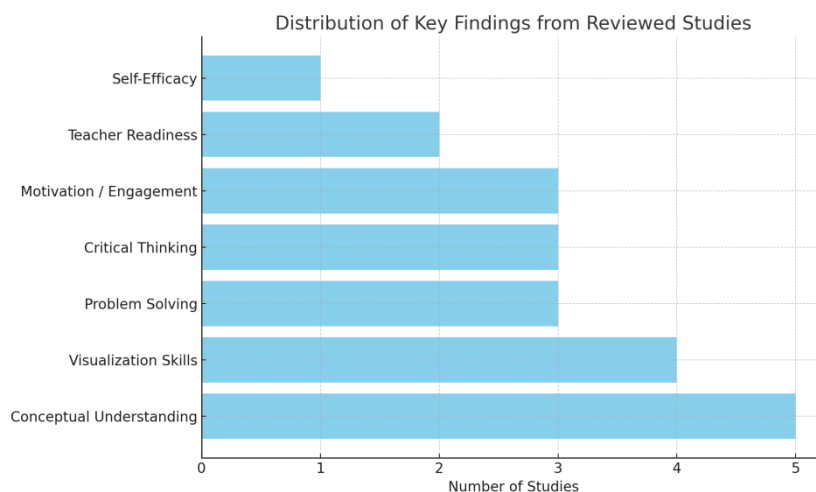
**Table 1.** Summary of Key Articles on GeoGebra in Mathematics Education

No	Author(s) & Year	Educational Level	Study Design	Key Findings
1	Putri & Subanji (2022)	Junior High	Quasi-Experimental	Improved representation skills
2	Julita et al. (2022)	Senior High	Experimental	High N-Gain in 3D conceptual understanding
3	Wijayanti & Permana (2023)	Senior High	Quasi-Experimental	Enhanced critical thinking and engagement
4	Herlina (2021)	All Levels	Qualitative	Need for teacher training to utilize GeoGebra
5	Giovanti et al. (2024)	Senior High	Experimental	Increased problem-solving ability

6	Rachmadtullah et al. (2022)	Junior High	Descriptive Survey	Effective in maintaining student participation
7	Usman et al. (2023)	Senior High	Quantitative Survey	Positive motivation, improved learning outcomes
8	Arjana (2022)	University	Mixed Methods	Increased self-efficacy in calculus
9	Rismaini & Devita (2022)	Elementary	Developmental	Motivated students in learning geometric shapes
10	Rivaldiansyah et al. (2024)	Junior High	Experimental	Improved understanding of congruence concepts

As illustrated in Table 1, the application of GeoGebra spans all education levels—from elementary to university and is adaptable to various instructional designs. A recurring finding across most studies is the significant improvement in students’ mathematical understanding and engagement when GeoGebra is utilized effectively. Notably, multiple studies have emphasized the importance of teacher training and infrastructure readiness in optimizing the use of GeoGebra in classroom settings.

To further illustrate the trends found in the literature, the results were categorized into dominant outcome themes. These themes include: conceptual understanding, visualization skills, critical thinking, problem-solving, motivation, teacher readiness, and self-efficacy. The number of studies that reported each theme is displayed in Figure 1.



**Figure 1.** Distribution of Key Findings from Reviewed Studies

As shown in Figure 1, the most frequently cited benefit of GeoGebra use was enhanced conceptual understanding, which was reported in five studies. This suggests that the interactive and visual features of GeoGebra are particularly effective in helping students grasp abstract mathematical concepts. Visualization skills were the second most emphasized outcome, appearing in four studies. GeoGebra’s ability to dynamically connect symbolic and graphical representations likely contributes to this effect.

Problem-solving ability and critical thinking were each discussed in three studies, demonstrating that GeoGebra not only facilitates knowledge acquisition but also supports higher-

order cognitive processes when used in constructivist learning environments. Non-cognitive outcomes such as motivation and self-efficacy, though less frequently mentioned, represent important dimensions of effective teaching and learning, especially in digital settings. Only two studies addressed teacher readiness, indicating a need for future research on teacher preparation and professional development in the context of digital instructional media.

In summary, the analysis of these ten studies reveals a robust body of evidence supporting the effectiveness of GeoGebra in enhancing both the quality of mathematics instruction and student outcomes. The trends in Table 1 and Figure 1 provide empirical justification for broader adoption and further investigation of GeoGebra in diverse educational contexts.

## **Discussion**

The findings of this systematic review provide compelling evidence that GeoGebra plays a transformative role in mathematics education, particularly in supporting conceptual understanding, visualization, and student engagement. Across the ten studies reviewed, GeoGebra consistently contributed to improved learning outcomes in both cognitive and affective domains. These findings are strongly aligned with the constructivist learning paradigm, which posits that learners build knowledge more effectively when they are actively engaged with manipulatives and visual representations (Ramadhan et al., 2021; Yulianti & Harahap, 2021).

The dominance of conceptual understanding as a reported outcome (identified in five studies) suggests that GeoGebra's integration of symbolic and graphical representations enhances students' ability to interpret abstract mathematical concepts. Through real-time visualizations and dynamic manipulation, students can explore mathematical relationships rather than passively receiving information. This is in line with previous assertions by Hohenwarter and Fuchs (2004), who emphasized the potential of GeoGebra to bridge the gap between concrete experience and formal abstraction.

Additionally, the review highlights that visualization skills were significantly developed in four studies. The ability to dynamically link geometric figures, functions, and equations in a single interface fosters the type of representational fluency advocated in current mathematics education standards. This is especially relevant in the context of topics such as geometry, algebra, and calculus, where visual reasoning is crucial.

Despite the clear cognitive benefits, the review also surfaces important implementation challenges. Only two studies addressed teacher readiness, yet both emphasized that the lack of technical competence and pedagogical familiarity with GeoGebra is a barrier to its effective use (Herlina, 2021; Irvan & Mushlihuddin, 2020). This gap indicates a systemic issue in professional development for mathematics educators, particularly in integrating digital tools meaningfully into classroom instruction.

Motivation and student engagement, although less frequently emphasized, are emerging themes that merit further attention. As digital natives, students often exhibit increased responsiveness to interactive technologies, and studies such as Usman et al. (2023) reported a significant positive shift in students' attitudes when GeoGebra was incorporated into lessons. However, the broader impact on non-cognitive outcomes such as persistence, interest in mathematics, and self-directed learning remains underexplored in the literature.

Furthermore, the role of GeoGebra in online or hybrid learning environments especially in response to the COVID-19 pandemic was discussed in studies such as Rachmadtullah et al. (2022),

which found GeoGebra to be effective in maintaining participation and instructional continuity. This aligns with broader global trends in the digitalization of education and highlights GeoGebra's adaptability across modalities.

A notable limitation across the studies is the lack of longitudinal research that evaluates the sustained impact of GeoGebra over time. Most studies relied on short-term interventions or post-test comparisons, which may not capture the deeper learning trajectories and long-term retention of mathematical concepts. Moreover, the studies are geographically limited, with a strong concentration in Indonesian settings; thus, caution must be taken in generalizing the results to broader international contexts without further comparative research.

In light of these findings, it becomes evident that while GeoGebra holds significant potential as a tool for enhancing mathematics instruction, its success is contingent upon several contextual factors. These include adequate infrastructure, ongoing teacher training, alignment with curricular goals, and the presence of institutional support mechanisms. Without addressing these conditions, the integration of digital tools like GeoGebra may yield limited or inconsistent results.

Therefore, the use of GeoGebra should not be viewed as a standalone intervention but rather as part of a holistic digital learning strategy that includes pedagogical planning, capacity building, and policy-level commitment. Future studies should explore integrative frameworks that combine technological tools with instructional strategies, and investigate how GeoGebra affects not only academic achievement but also students' long-term mathematical identity and resilience.

## **CONCLUSION**

This systematic literature review aimed to examine the effectiveness of GeoGebra in mathematics education in the context of the digital era. By synthesizing findings from ten empirical studies published between 2020 and 2025, the study provides a comprehensive overview of how GeoGebra contributes to enhancing students' learning outcomes across various educational levels.

The findings consistently indicate that GeoGebra offers significant pedagogical advantages, particularly in improving conceptual understanding, visualization skills, problem-solving ability, and critical thinking. Its interactive features facilitate constructivist learning environments, allowing students to engage actively in exploring mathematical ideas. Moreover, several studies reported positive impacts on student motivation and engagement, reinforcing GeoGebra's value as a digital learning tool that aligns with 21st-century educational goals and the principles of Indonesia's Kurikulum Merdeka.

However, the review also identified several challenges that may hinder the optimal implementation of GeoGebra. These include limited teacher readiness, insufficient professional development, and infrastructural constraints, particularly in under-resourced schools. Furthermore, the literature reveals a lack of focus on non-cognitive outcomes and long-term effects, which should be addressed in future research.

In conclusion, GeoGebra demonstrates strong potential as an effective digital tool in mathematics instruction. Its implementation, however, must be supported by appropriate training, curricular integration, and systemic support to ensure meaningful and sustainable use. It is recommended that future research expand to include broader contextual variables, longitudinal designs, and deeper exploration of affective outcomes to fully understand the transformative potential of GeoGebra in mathematics education.

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