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Geometry Learning through GeoGebra in Mathematics Education: Trends, Effects, and Research Gaps (2020–2025)

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ABSTRACT

Geometry is fundamental in mathematics education for developing spatial reasoning and understanding abstract relationships. However, students often struggle with its abstract nature. Dynamic geometry software such as GeoGebra offers interactive visualization that can enhance conceptual understanding. This study aims to examine research trends, instructional strategies, and gaps in GeoGebra-based geometry learning. A systematic literature review (SLR) was conducted following PRISMA guidelines, complemented by bibliometric analysis using VOSviewer. From an initial pool of 119 studies published between 2020 and 2025, 15 articles were selected based on predefined inclusion criteria. The selected studies were analyzed to identify patterns in pedagogy, outcomes, and research focus. The findings indicate that GeoGebra effectively supports innovative instructional approaches, including project-based learning, problem-based learning, and flipped learning. Its use significantly improves students' conceptual understanding of geometry, particularly in topics such as geometric transformations. Additionally, GeoGebra enhances students' motivation, confidence, and engagement in learning mathematics. Despite these benefits, the integration of GeoGebra with culturally contextualized learning remains limited. Few studies address basic geometric concepts, such as lines and angles, within local cultural contexts (e.g., traditional dance patterns), indicating an underexplored area in current research. GeoGebra is a powerful tool for enhancing geometry learning; however, future research should focus on developing culturally responsive, technology-integrated approaches to bridge existing gaps and enrich mathematics education.

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1. INTRODUCTION

Geometry is one of the key topics in mathematics education, playing a crucial role in building students' understanding of spatial concepts and mathematical relationships. Geometry as the foundation for various applications in disciplines such as design, technology, and computer science (Meryansumayeka et al., 2022; Prahmana et al., 2024). Geometry is a cultural and physical subject in addition to a mathematical one. For instance, using dance to teach geometry shows how students' intuitive sense of space and movement can be used to depict and comprehend geometric concepts like auxiliary lines (Apsari & Abrahamson, 2024). However, this topic is often considered challenging for students due to its abstract nature and the high level of visual thinking skills (Martinez & Garcia, 2018). Research shows that integrating technology, such as Students can alter geometric shapes with dynamic geometry software, which improves their ability to visualize and comprehend the characteristics of lines and angles. Because learners can observe the direct consequences of transformations and reflections on shapes, this interactive approach allows students to investigate geometric concepts in a more interesting and intuitive way (Segal et al., 2021; Valori et al., 2022). Furthermore, technology-based learning not only improves academic outcomes but also fosters positive attitudes toward mathematics learning (Davis & Lee, 2021). Through innovative and interactive approaches, the challenges of teaching geometry can be addressed, enabling students to better understand and apply these concepts.

In recent decades, educational technology such as GeoGebra has emerged as an interactive tool to support mathematics learning, including geometry. GeoGebra provides a dynamic visual environment that allows students to manipulate and explore geometric objects directly, bridging the gap between mathematical abstraction and visual reality (Küçük & Gün, 2023; Makamure & Mukamba, 2020). Studies have shown that the use of GeoGebra significantly enhances students' conceptual understanding of mathematics, learning motivation, and positive attitudes toward mathematics (Dahal et al., 2022; Asare & Atteh, 2022Students may visualize and work with geometric concepts using GeoGebra's interactive capabilities, which helps them comprehend abstract concepts like lines and angles. Students can better understand the links between various geometric elements by, for example, seeing real-time changes in geometric figures when they modify parameters (Maltildis et al., 2025; Ndagijimana et al., 2024). With the increasing use of GeoGebra in classrooms, numerous studies continue to evaluate its effectiveness, design learning activities, and identify challenges and opportunities associated with its application in mathematics education (Küçük & Gün, 2023; Dahal et al., 2022).

Although much research has been conducted on GeoGebra-based learning, a comprehensive systematic review of the literature related to geometry has not yet been conducted. GeoGebra, with its dynamic visual environment, enables students to manipulate geometric objects directly, bridging the gap between mathematical abstraction and visual reality (Dahal et al., 2022; Condori et al., 2020). It has been discovered that GeoGebra increases students' enthusiasm and favorable attitudes toward studying geometry. GeoGebra boosted students' interest in geometry, according to more than half of the assessed research (Uwurukundo1 et al., 2022). However, a deeper systematic review is needed to evaluate GeoGebra-based teaching methods, assess the success of instructional strategies, and identify existing research gaps. Such a review is essential to provide recommendations for future research and to assist educators in maximizing the use of this technology in teaching geometry (Yohannes & Chen, 2021; Muslim et al., 2023).

This study addresses three main questions that serve as a framework for analyzing the literature on transformation geometry learning using GeoGebra. The first question focuses on mapping the profile of the literature, including the distribution of publications, researcher contributions, keyword analysis, and research methodologies, to provide a global insight into prevailing trends and approaches. The second question evaluates the instructional design, covering content such as geometry (e.g., real-world applications or visual simulations), and the effectiveness of GeoGebra features and instructional strategies such as independent exploration or collaboration in supporting students' understanding. The third question identifies research gaps, such as cultural relevance and students' needs, as well as the limitations of GeoGebra. Recommendations are provided to enhance GeoGebra's features, develop innovative designs, and integrate cultural contexts to enrich technology-based mathematics learning.

2. METHODS

This systematic literature review (SLR) followed PRISMA 2020 guidelines for transparency and reproducibility. The Systematic Literature Review (SLR) method was used in this study. It was meticulously and methodically planned using a number of steps, such as finding, assessing, interpreting, and drawing conclusions from earlier research findings that were pertinent to and in line with the current study's focus (Nuridayanti et al., 2025).

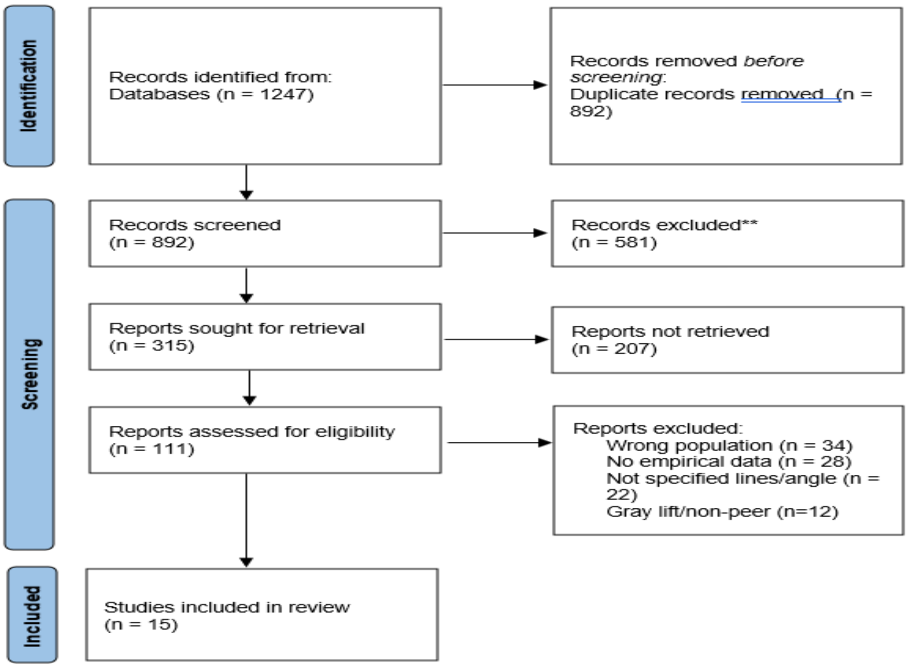

Figure 1. PRISMA Selection Process

2.1 Article Selection Process

The article selection process in this study followed the PRISMA guidelines (Preferred Reporting Items for Systematic Reviews and Meta-Analyses), consisting of four main stages: identification, screening, eligibility assessment, and inclusion.

1. Identification of Studies (n = 119)
   In the first stage, a systematic search was conducted through various data sources, including electronic databases such as Publish or Perish and gray literature (e.g., research reports, dissertations, or conference proceedings). A total of 119 articles were identified during the initial search, covering various studies relevant to the analyzed topic.
2. Screening (n = 30)
   Of the 119 articles identified, screening was carried out based on inclusion and exclusion criteria. This stage eliminated irrelevant, duplicate, or low-quality articles. After the screening process, 30 articles remained that met the basic criteria for further analysis.
3. Eligibility Assessment (n = 24)
   Articles that passed the screening stage underwent a full-text eligibility assessment, where stricter criteria were applied. The researchers examined the methodology, sample, and reported results in each study. From the 30 screened articles, only 24 met the criteria for full-text eligibility assessment.
4. Inclusion (n = 15)
   After the full-text assessment, only studies that were highly relevant and of high quality were included in the systematic review or meta-analysis. A total of 15 studies were ultimately selected for

the final analysis, based on their alignment with the research questions and appropriate methodologies.

By following the PRISMA flow, this study aims to produce a transparent, systematic, and reliable review of the literature. Additionally, the number of studies processed at each stage provides a clear overview of the selectivity and quality of the literature included in this review.

2.2 Utilizing VOSviewer for Data Analysis

The last step was to use VOSviewer, a program for creating and displaying bibliometric networks, to analyze the bibliometric data of the chosen publications (Padwiansyah et al., 2023). Through keyword co-occurrence, co-citation analysis, bibliographic coupling, and network visualization, VOSviewer allows researchers to examine patterns and connections across extensive collections of scientific literature.This tool was used to map patterns in the Geometry Learning through GeoGebra research conducted between 2020 and 2025, assisting in the identification of recurring terminologies, dominant themes, and links between studies. The result consists of network, overlay, and density visualizations that show how the field of Geometry Learning through GeoGebra has evolved and where more study is required.

3. FINDINGS AND DISCUSSION

3.1 Findings

VOSviewer was used to perform a bibliometric study in order to gain a thorough grasp of research trends in geometry learning using GeoGebra. Three types of visualizations were produced by the analysis: network visualization, density visualization, and overlay visualization. Together, these visualizations show the temporal evolution, research intensity, and theme organization of works pertaining to GeoGebra in mathematics education.

Network visualization, density visualization, and overlay visualization are used to assess the article.In a network visualization, objects are represented by networks and labels, and the number of items determines the size of the item circles and labels. The overlay graphic shows the year that the item-related study was conducted. It is designed to show color changes; the more recent the research, the brighter (yellow) an item group's color. In the meantime, density visualization shows the density of objects; the more items there are, the closer the color is to red (Sjögårde, 2022; Xue et al., 2024).

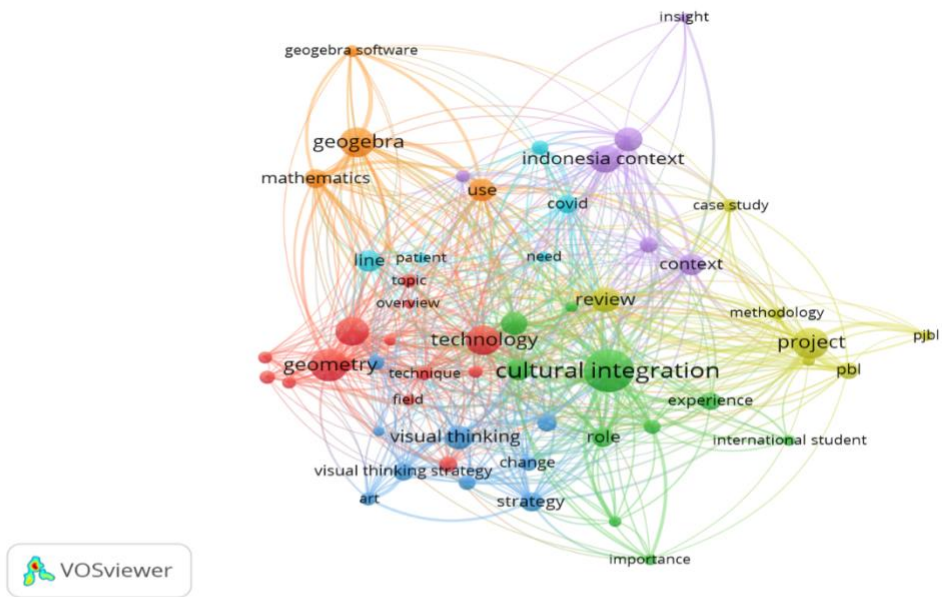

Figure 2. Network Visualization Result

The network visualization highlights many topic clusters that define the structure of research in GeoGebra-based geometry learning and shows the relationships between terms. Keywords like GeoGebra, mathematics, GeoGebra software, and use indicate the first cluster, which is focused on GeoGebra and learning mathematics. This cluster shows that the use of GeoGebra as a digital tool to enhance math instruction is a major focus of the literature. The extensive use of GeoGebra as a dynamic mathematics program that enables interactive mathematical concept exploration and visualization is demonstrated by the strong correlations between these terms.

Keywords like geometry, visual thinking, and visual thinking approach are included in the second cluster, which is related to learning geometry and visual thinking. This cluster highlights how GeoGebra helps students develop their spatial thinking and visualization skills, which are essential for comprehending geometric relationships and structures. Another cluster, denoted by the phrase technology, emphasizes the use of technology in mathematics instruction. GeoGebra is frequently discussed within the larger discourse of digital change in education, as evidenced by the connections this cluster makes between various research subjects.

A notable cluster of phrases like "cultural integration," "role," and "experience" also emerges. This cluster appears to have little link to the GeoGebra and geometry clusters, despite being visible in the network. This pattern suggests that there is still a lack of information on the integration of cultural perspectives into GeoGebra-based geometry education. Additionally, project-based learning is associated with a smaller cluster represented by terminology like project, PBL, and PJBL. This cluster demonstrates how some studies try to combine GeoGebra with student-centered teaching methods. However, the tiny size and connections of this cluster indicate that research integrating GeoGebra with innovative teaching methods is still in its infancy.

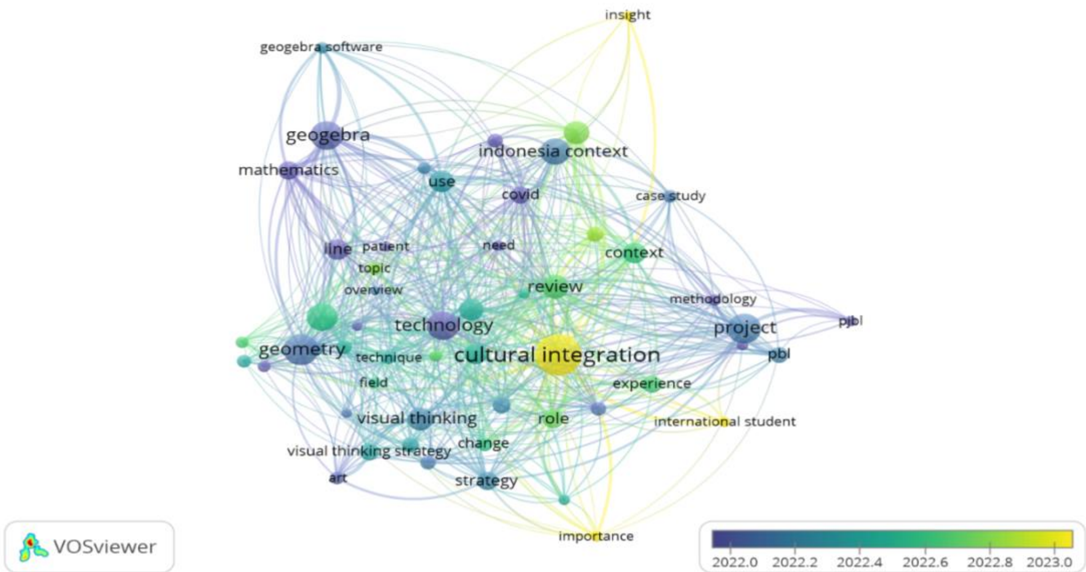

Figure 3. Overlay Visualization Result

The overlay graphic sheds light on how research topics have changed throughout time. Previous study themes, denoted by darker hues, include terms like geometry, mathematics, and GeoGebra. The main goal of these experiments was to determine how well GeoGebra works as a technological tool for visualizing mathematical ideas and enhancing students' conceptual comprehension. Brighter colors denote more recent subjects, such as international students, context, cultural integration, and projects. This implies that more comprehensive pedagogical and contextual aspects of learning mathematics have started to be investigated in recent research. A growing interest in tying mathematics education to students' cultural backgrounds and real-world situations is reflected in the rise of keywords associated with cultural integration. Nonetheless, the very poor connection between these terms and certain geometry subjects suggests that this integration is still restricted.

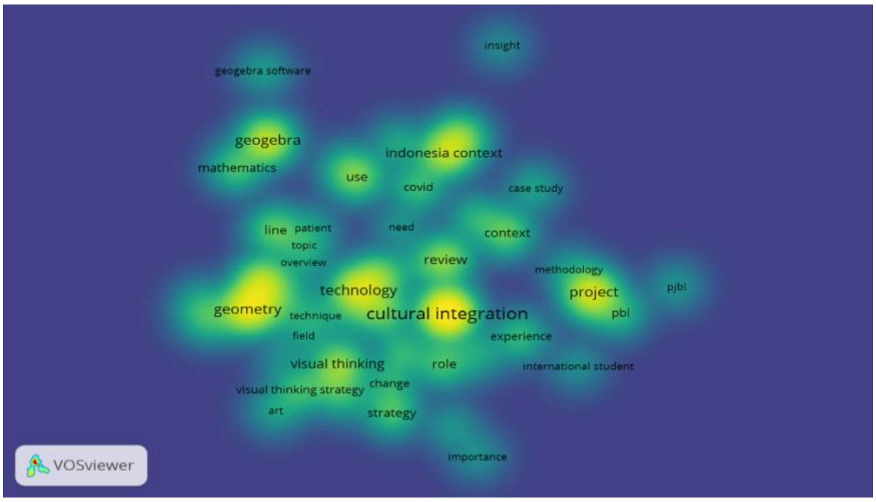

Figure 4. Density Visualization Result

The density graphic uses co-occurrence and keyword frequency to show the intensity of study subjects. Keywords like GeoGebra, geometry, technology, project, and cultural integration are examples of highly concentrated areas, which are shown by brighter hues. This suggests that there has been extensive discussion of these subjects in the literature.

The majority of research concentrate on the use of dynamic geometry software to promote conceptual comprehension and visualization in geometry learning, which is confirmed by the high density of GeoGebra and geometry. In a similar vein, the increasing use of digital technologies in mathematics instruction is reflected in the popularity of the keyword technology. However, a number of keywords, including context, experience, and visual thinking technique, are found in lower density locations. This implies that while visualization is often mentioned, there is still a dearth of research that focuses on educational approaches for encouraging visual thinking with GeoGebra.

Furthermore, compared to technology terms, contextual learning-related keywords seem less prevalent. This suggests that there are still few studies including regional cultural backgrounds into GeoGebra geometry instruction. Research that links GeoGebra-based instruction with regional cultural artifacts or practices to enhance comprehension of basic geometry concepts like lines and angles is particularly lacking.

Table 1. Summary of Reviewed Studies on GeoGebra in Geometry Learning

Author	Country	Sample	Method	Geometry Topic	Instructional Strategy	Key Findings
Birgin & Topuz (2021)	Turkey	7th grade students	Quasi-experimental (pretest–posttest)	Geometry concepts	GeoGebra-supported collaborative learning	GeoGebra in a CSCL environment significantly improved students' geometry achievement, retention, and attitudes compared with textbook-based instruction.
Kholid et al. (2022)	Indonesia	137 preservice mathematics teachers	Quasi-experimental	Analytical geometry	GeoGebra Project-Based	Geo-PJBL supported better conceptual understanding of

					Learning (Geo-PJBL)	transformation and distance topics due to improved visualization.
Chen et al. (2021)	China	University students	Experimental study	Geometry visualization	GeoGebra-based learning	GeoGebra improved conceptual understanding through interactive visual representations.
Nasir et al. (2023)	Malaysia	60 secondary school students	Non-equivalent group design	Polygon geometry	GeoGebra-assisted instruction	Students using GeoGebra showed higher achievement and engagement than those using conventional methods.
Dahal et al. (2022)	Nepal	Secondary students	Experimental	Geometry learning	GeoGebra-based instruction	GeoGebra significantly enhanced students' conceptual understanding and motivation in learning geometry.
Kounlaxay et al. (2021)	Laos	Secondary school students	Experimental	Solid geometry	GeoGebra integrated with Augmented Reality	Integration of GeoGebra and AR improved engagement and spatial understanding of 3D concepts.
Isharton o et al. (2022)	Indonesia	Under graduate students	Experimental	Geometry learning	Flipped learning with GeoGebra	GeoGebra-supported flipped learning improved self-regulated learning and conceptual understanding.
Ndagijimana et al. (2024)	Rwanda	Secondary students	Quasi-experimental	Geometric concepts	Dynamic geometry learning	GeoGebra improved visualization skills and helped students understand geometric relationships.
Prince (2024)	USA	Undergraduate students	Experimental	Geometry concepts	Technology-enhanced learning	GeoGebra increased student engagement and conceptual understanding in mathematics.
Silva et al. (2025)	Brazil	University students	Development study	Geometry learning	GeoGebra integrated with digital platforms	Integration of GeoGebra with digital learning systems created interactive and student-centered environments.
Fernandes (2024)	Portugal	Mathematics teachers	Professional development study	Geometry teaching	Teacher training with GeoGebra	Professional training programs improved teachers' ability to design technology-

						integrated geometry instruction.
Saputri et al. (2025)	Indonesia	Secondary students	Experimental	Geometry concepts	Contextual learning with GeoGebra	GeoGebra helped connect mathematical concepts with real-world contexts.
Mokotjo & Mokhele (2021)	South Africa	Secondary teachers and students	Case study	Geometry teaching	Technology integration	Implementation challenges included limited infrastructure and insufficient teacher training.
Yohannes & Chen (2021)	China	Secondary students	Experimental	Geometry learning	GeoGebra-assisted learning	GeoGebra enhanced students' visualization and problem-solving abilities in geometry.
Condori et al. (2020)	Peru	Secondary students	Experimental	Geometric transformations	Dynamic geometry environment	GeoGebra helped students understand geometric transformations through direct manipulation of objects.

Based on the analysis of 15 relevant articles, research on the use of GeoGebra in mathematics education has shown significant growth over the past decade. Most of these studies were published in international journals focusing on mathematics education and educational technology, with the majority employing a quasi-experimental approach to evaluate the impact of GeoGebra on students' conceptual understanding and academic achievement (Birgin & Topuz, 2021; Kholid et al., 2022). Other studies used case study designs to explore students' learning experiences more deeply, highlighting the role of GeoGebra in supporting collaborative learning environments (Birgin & Uzun Yazıcı, 2021; Wen & Bajuri, 2025; Pinto & Notare, 2023). The main themes explored in these studies include the application of GeoGebra in teaching geometric such as translation, rotation, reflection, and dilation and its integration with innovative approaches, such as project based learning and technological enhancements, to support mathematics education (Kounlaxay et al., 2021; Condori et al., 2020).

GeoGebra has proven to be highly effective in facilitating the teaching of geometric, particularly through its dynamic visualization capabilities, which enable students to intuitively understand the relationships between geometric objects and their properties (Birgin & Topuz, 2021; Dahal et al., 2022; Schmid et al., 2023; Li & Li, 2023). By allowing students to directly manipulate geometric objects, GeoGebra helps bridge the gap between abstract mathematical concepts and concrete visual representations. Furthermore, GeoGebra supports various innovative instructional approaches, such as Project-Based Learning, Problem-Based Learning, and flipped learning, which allow for deeper and more contextual explorations of mathematical concepts (Kholid et al., 2022; Ishartono et al., 2022). In collaborative learning environments, GeoGebra has demonstrated positive impacts not only on students' academic performance but also on their information retention (Birgin & Uzun Yazıcı, 2021; Iradukunda & Mugiraneza, 2024; Prince, 2024).

Several studies also explored the integration of GeoGebra with other technologies, such as Augmented Reality (AR), to enrich learning experiences. Research by Kounlaxay et al. (2021) revealed that the combination of GeoGebra and AR enhances student engagement and helps them understand more complex concepts through interactions in three-dimensional spaces. Additionally, GeoGebra has had a significant impact on the development of students' independent learning skills. A study by Ishartono et al. (2022) found that flipped learning approaches supported by GeoGebra helped students become more self-regulated in managing their learning processes, particularly during the COVID-19 pandemic. GeoGebra not only fosters students' self-regulation skills but also creates an interactive and enjoyable learning environment, thereby reducing students' anxiety toward mathematics and improving their confidence in learning (Zetriuslita et al., 2020). The creation of student-centered learning environments is aided by the usage of GeoGebra in conjunction with other digital platforms, which improves comprehension and engagement (Silva et al., 2025). Teachers can be empowered to create transformative learning opportunities and promote a deeper comprehension of mathematical topics through professional development programs that emphasize the integration of GeoGebra and other technologies (Fernandes, 2024).

However, several research gaps need further exploration. Most studies have yet to investigate the potential integration of GeoGebra into local cultural contexts, despite the promising opportunities this approach offers to enrich students' learning experiences (Birgin & Topuz, 2021; Kholid et al., 2022; Saputri et al., 2025; Ndagijimana et al., 2024). Moreover, technical challenges such as a lack of teacher training and limited technological infrastructure have been reported as barriers to the implementation of GeoGebra in certain regions (Dahal et al., 2022; Mokotjo & Mokhele, 2021). Students with low spatial visualization skills also require additional support to fully utilize GeoGebra. Therefore, further research is needed to develop more inclusive and contextualized instructional designs to maximize GeoGebra's potential in supporting mathematics education.

3.2 Discussion

The findings of this systematic literature review (SLR) indicate that the use of GeoGebra in mathematics education has become a prominent focus over the past decade, primarily due to its ability to support dynamic visualization and innovative instructional approaches. Research, predominantly employing quasi-experimental methods, consistently reports the positive impact of GeoGebra on students' conceptual understanding and academic achievement. This demonstrates that GeoGebra effectively bridges the gap between mathematical abstraction and tangible visual experiences, particularly in the context of geometric. This effectiveness aligns with the findings of Birgin & Topuz (2021) and Dahal et al. (2022), which highlight GeoGebra's role in simplifying the exploration of concepts such as translation, rotation, reflection, and dilation through direct manipulation of geometric objects.

GeoGebra's ability to support various innovative instructional approaches, such as project-based learning, problem-based learning, and flipped learning, is one of its core strengths. These approaches enable students to explore mathematical concepts in more contextualized and practical ways. For example, project-based learning with GeoGebra provides students with opportunities to solve real-world problems and develop critical thinking skills (Kholid et al., 2022). In flipped learning environments, GeoGebra has been shown to foster self-regulation by encouraging more independent and structured learning, particularly during the COVID-19 pandemic (Ishartono et al., 2022). This underscores GeoGebra's flexibility in integrating with diverse pedagogical methods.

Beyond supporting conceptual understanding, GeoGebra also positively influences students' attitudes toward mathematics. Reducing learning anxiety and increasing students' confidence are significant aspects frequently reported in the literature. A study by Zetriuslita et al. (2020) revealed that the interactive and engaging learning environment facilitated by GeoGebra creates more meaningful and enjoyable learning experiences for students. This is crucial, as mathematics anxiety often poses a significant barrier to effective learning.

The integration of GeoGebra with other technologies, such as Augmented Reality (AR), broadens the scope of teaching and learning applications. For instance, research by Kounlaxay et al. (2021) demonstrates how combining GeoGebra with AR enhances student engagement and deepens their understanding of more complex geometric concepts. While this technological integration remains limited in the literature, these findings present significant opportunities for further exploration.

Nevertheless, there are challenges and gaps that warrant attention. Most studies have not yet explored the potential of using GeoGebra in local cultural contexts. Integrating GeoGebra with cultural elements, such as traditional geometric patterns, could enrich learning experiences and create more meaningful education for students. In addition, studies that are now available seldom concentrate on particular geometry issues, especially lines and angles, within regional cultural contexts like traditional dances. Research linking GeoGebra-based geometry learning with cultural representations of lines and angles seen in regional dances is still extremely restricted, despite the fact that cultural integration has started to garner attention in mathematics education. This suggests that there is a substantial study gap regarding the ways in which cultural practices, including traditional dance patterns and movements, might function as significant contexts for comprehending basic geometric notions like lines and angles. Furthermore, technical challenges, such as insufficient teacher training and limited technological infrastructure in certain regions, remain significant barriers that must be addressed to ensure the effective implementation of GeoGebra. Students with low spatial visualization skills also require additional strategies to fully utilize GeoGebra, highlighting the need for more inclusive instructional designs.

Overall, GeoGebra holds substantial potential to support more interactive, innovative, and meaningful mathematics education. Further research is needed to investigate how GeoGebra can be integrated into culturally contextualized learning and how instructional designs can be adapted to overcome existing implementation challenges. Since lines and angles are often found in cultural items and performances like traditional dances, future research is urged to investigate how GeoGebra might be integrated with local cultural contexts to teach basic geometry concepts. Addressing these gaps will enable GeoGebra to become a more inclusive and relevant tool, supporting the diverse needs of students across various educational contexts.

4. CONCLUSION

The use of GeoGebra in mathematics education, particularly in the context of geometric, demonstrates a significant impact on improving students' understanding of abstract concepts. GeoGebra, with its dynamic visualization capabilities, facilitates the bridging of mathematical abstraction with tangible visual experiences. The studies analyzed in this review consistently report improvements in conceptual understanding, academic achievement, and student motivation toward mathematics learning. Moreover, GeoGebra supports various innovative approaches, such as project-based learning, problem-based learning, and flipped learning, offering more contextualized and practical learning experiences.

GeoGebra has also proven to create interactive and enjoyable learning environments, effectively reducing students' anxiety toward mathematics and boosting their confidence. The ability to integrate GeoGebra with other technologies, such as Augmented Reality, expands its potential in delivering deeper and more engaging learning experiences. However, several challenges remain in implementing GeoGebra, including a lack of teacher training, limited technological infrastructure, and gaps in its application for students with low spatial visualization skills.

Additionally, the potential integration of GeoGebra with local cultural contexts has been largely unexplored. Furthermore, specific geometry issues like lines and angles while using GeoGebra are rarely the focus of previous studies. There is currently very little research that combines GeoGebra-based geometry instruction on lines and angles with regional cultural settings, such as through representations seen in traditional dances. Given that cultural practices like regional dance patterns may offer insightful depictions of geometric relationships involving lines and angles, this suggests a sizable gap in the literature. Future research could focus on developing more inclusive and culturally relevant instructional designs to maximize the impact of GeoGebra in addressing the diverse needs of students. Consequently, GeoGebra holds great potential as a learning tool that not only supports academic achievement but also fosters engagement, motivation, and the relevance of mathematics education across various educational contexts.

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