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Students' Spatial Ability in GeoGebra-Assisted Mathematics Learning: A Systematic Literature Review

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Abstract: *Spatial ability is a curriculum requirement that must be accommodated in mathematics learning. This study aims to systematically examine students' spatial abilities in GeoGebra-assisted mathematics learning. The study was conducted using the Systematic Literature Review (SLR) method on 12 research articles from 2020–2025 and obtained through the Google Scholar and Crossref database with the help of the Publish or Perish application. The results of the study indicate that the research trend of students' spatial abilities in GeoGebra-assisted mathematics learning has increased in the last five years with a focus on the application of various innovative learning models such as Realistic Mathematics Education (RME), Problem-Based Learning (PBL), Project-Based Learning (PjBL), Van Hiele, and Discovery Learning. In conclusion, the integration of GeoGebra in mathematics learning is flexible, interactive, and relevant as an innovative strategy to strengthen students' spatial abilities.*

Keywords: *systematic literature review, spatial ability, mathematics learning, GeoGebra*

INTRODUCTION

Education plays a crucial role in human life because it serves as the primary foundation for building a quality life, shaping character and morals, and is a fundamental human right (Nisa & Arumdati, 2024). Mathematics learning is part of the education provided in schools and plays a crucial role in the world of education. NCTM (2000) states that there are five content standards in mathematics standards: numbers and their operations, algebra, geometry, measurement, probability, and data analysis. Spatial ability is a curriculum requirement that must be accommodated in classroom learning because geometry contains elements of visualization, spatial reasoning, and modeling (Parangin-angin et al., 2021). Based on data from the PISA (Programme for International Student Assessment) conducted by the OECD (Organization for Economic Co-operation and Development) in 2022, Indonesia achieved a score of 366 for mathematics ability, ranking 68rd out of 81 countries. According to Ningsih & Susanta (2022), the mathematics content in PISA consists of four components: probability and data, change and relationships, space and shape, and numbers. However, the space and shape content obtained low scores compared to the scores for other content (Oktaviana & Rosyidi, 2019). It can be concluded that the space and shape content is the most difficult content. Where space and shape content is the content of questions related to geometry. Based on the results of the PISA question analysis on the space and shape content, only 33.4% of students were able to answer correctly (Asdarina & Ridha, 2020). These low results are a result of students' low spatial abilities. According to Sholihah et al. (2019), students' spatial abilities influence PISA scores in the space and shape content. This is because students still struggle to construct geometric shapes, especially when solving problems with visualization. Visualization is one element of spatial ability.

Spatial ability is related to cognitive activities in seeing and building relationships between an object and its surrounding environment (Sudirman & Alghadari, 2020). Spatial ability is defined as the ability or skill used to change or manipulate an object mentally (Lowrie et al., 2019). Spatial ability is important for students to master because this ability emphasizes the field of geometry (Azzahra et al., 2025). Learning mathematics is certainly inseparable from geometry, therefore with good spatial ability, mathematical ability will also be good, especially in the field of geometry (Kusnadi et al., 2023). Without spatial ability, students will have difficulty constructing geometric concepts into other disciplines and everyday life. The spatial ability indicators used in this study refer to spatial ability according to Maier (2001), namely 1) spatial perception; 2) rotation; 3) spatial visualization; 4) spatial orientation; and 5) spatial relations.

The mathematics learning process still shows that not many teachers have succeeded in creating conditions and situations that can train students to develop spatial thinking skills. Yet, this ability is crucial in supporting the teaching and learning process and helping students understand and recognize their surroundings. One important aspect of spatial thinking skills is understanding spatial relationships, which is a crucial component in mathematics learning, particularly geometry. Students' low spatial ability is one of the main causes of their difficulty in understanding geometry material. Given that geometry is an important part of mathematics, this problem certainly needs to be addressed immediately to improve learning effectiveness (Usman et al., 2020). In line with Safira et al. (2022), who stated the importance of more in-depth learning and spatial thinking exercises to help students overcome difficulties in understanding geometry. Furthermore, the learning tools used do not support the development of students' spatial abilities, which impacts their low spatial abilities. This ability plays a crucial role in learning, especially geometry. Students with low spatial abilities will experience difficulties and lack enthusiasm, resulting in a passive learning process. The use of media or aids can help improve learning achievement, both inside and outside the classroom (Fathia & Yerizon, 2022).

Innovation in learning is crucial for improving students' spatial abilities. By utilizing technology combined with real-world problems, it is hoped that students' confidence in understanding spatial shapes will increase and, ultimately, develop their spatial abilities. Furthermore, technology-based media are needed to facilitate students' discovery of concepts, particularly spatial shapes. GeoGebra, as an interactive mathematical software, has not been optimally utilized in classroom learning. This situation indicates the need to explore new approaches, such as those cited by Nurwijaya (2022), who emphasized that using technology is one of the most efficient approaches to overcoming mathematical difficulties. With the help of GeoGebra software, students can visualize spatial concepts interactively, thereby strengthening their understanding.

Various studies have shown that GeoGebra can help improve students' visualization and spatial abilities in mathematics learning. However, these studies are still scattered across various publications with diverse characteristics, and therefore have not yet provided a systematic and comprehensive overview of the development of research in this area. To date, there have been only limited *Systematic Literature Review* (SLR) studies that specifically examine students' spatial abilities in GeoGebra-assisted mathematics learning, particularly in mapping the trends of learning models employed, educational levels investigated, and dominant research findings. Previous studies generally reviewed the use of GeoGebra in mathematics learning in a broader sense without specifically focusing on spatial ability aspects. Therefore, this study was conducted to address this gap through an SLR approach in order to present a more structured mapping of research related to students' spatial abilities in GeoGebra-assisted mathematics learning. The novelty of this study lies in its specific focus on integrating the analysis of spatial abilities, the use of GeoGebra, learning models, and educational levels within a single comprehensive literature review.

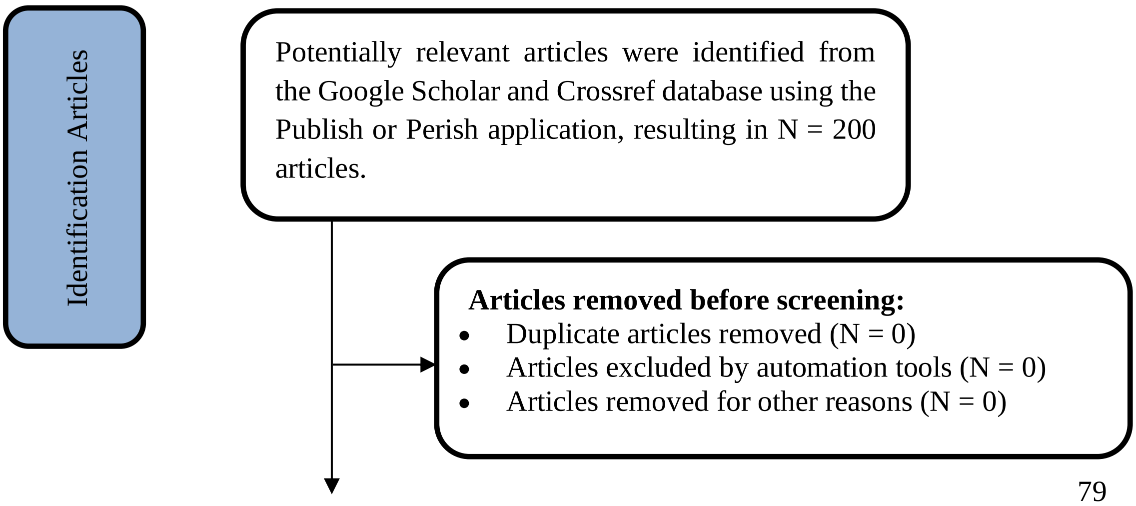
Based on the background description that has been explained, this study aims: (1) to describe research trends in 2020–2025 related to students' spatial abilities in GeoGebra-assisted mathematics learning; (2) to determine students' spatial abilities in GeoGebra-assisted mathematics learning. Where this literature review also identifies various learning models that can be integrated with GeoGebra, which is expected to provide an overview of what learning models can be used to improve spatial abilities. In addition, this study also maps the educational levels that are most often the focus of research. Through the results of this mapping, this study is expected to provide new contributions in the form of recommendations for further research in order to develop studies at educational levels that are still rarely researched, so that the use of GeoGebra in mathematics learning can be applied more widely, effectively, and evenly across various educational levels.

METHOD

The method used in this research is a Systematic Literature Review (SLR). A Systematic Literature Review is a method used to determine, evaluate, and interpret all research problem findings to answer established questions (Rachmawati et al., 2021). The purpose of using the SLR method in this method is to identify and summarize various previous research results related to students' spatial abilities in GeoGebra-assisted mathematics learning. In the process of identifying and reviewing this research, the SLR research steps proposed by Triandini et al (2019) were used.

The first step is to determine the Research Question (RQ) or research questions that are compiled based on the needs of the specified research topic. The RQ in this study are: (RQ1) What is the research trend in 2020 - 2025 regarding students' spatial abilities in GeoGebra-assisted mathematics learning?; (RQ2) What are the research results regarding students' spatial abilities in GeoGebra-assisted mathematics learning?.

The second step is the search process. The search process is the step of finding relevant data sources to use in answering the RQ. The process of searching for relevant data sources is through the Google Scholar and Crossref database with the help of the Publish or Perish application. The keywords used were "spatial ability in GeoGebra-assisted mathematics learning" for the period 2020–2025. Articles were included if they explicitly examined spatial ability variables, implemented GeoGebra as an intervention or learning media in mathematics learning, and reported empirical research findings. The stages of article selection in this study are presented in the PRISMA flow diagram shown in Figure 1.



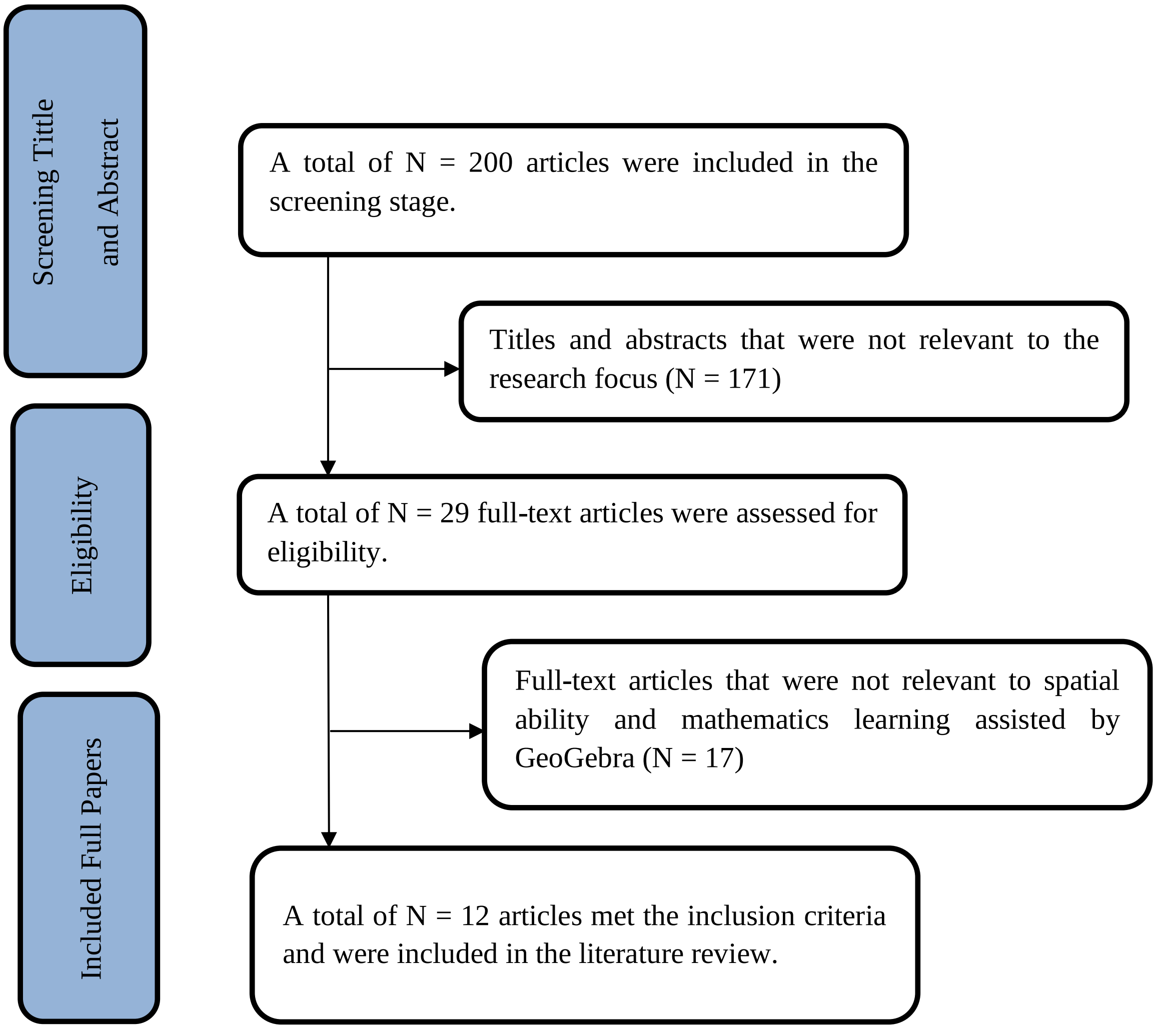


Figure 1. PRISMA Flow Diagram

The third step is Inclusion and Exclusion Criteria. This step is used to determine whether the obtained literature is suitable for use in the research. The eligibility criteria for this study are presented in Table 1 below.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
The literature consists of journal articles or conference proceedings.	The literature is not in the form of journal articles or conference proceedings.
The publication years are 2020–2025.	The publication year of the literature was before 2020.
International and national literature related to spatial abilities in GeoGebra-assisted mathematics learning.	The international and national literature is not related to spatial abilities in GeoGebra-assisted mathematics learning.
The literature was obtained from Google Scholar and Crossref.	The literature was obtained from sources other than Google Scholar and Crossref.
The research participants were students.	The research participants were not students.

The fourth step is Quality Assessment (QA). This step is conducted to evaluate the obtained literature based on QA criteria. In this study, the QA criteria specified include: (QA1) Is the literature a journal article or conference proceedings? (QA2) Was the literature published between 2020 and 2025? (QA3) Does the international or national literature discuss spatial abilities in GeoGebra-assisted mathematics learning? (QA4) Was the literature obtained from Google Scholar and Crossref? (QA5) Were the research participants students? (QA6) Does the article explicitly describe the aims of the research? (QA7) Is the research methodology suitable for assessing students' spatial abilities? (QA8) Are the quantity, educational level, and participant characteristics clearly presented in the study?. With the established QA criteria, literature that meets all QA criteria is eligible for use as a reference for this study.It is best to avoid organizing writing into "sub-headings" in this section. However, if it cannot be avoided, the method of writing can be seen in the "Results and Discussion" section.

The fifth step is Data Collection. In this step, the researcher collects literature to be used in the research based on the specified QA criteria. The sixth step is Data Analysis. After obtaining the literature, the next step is analyzing the obtained data to answer the established RQs. The seventh step is Deviation from Protocol. Refine word equivalents to match keywords in the database.

RESULTS AND DISCUSSION

The literature search process was conducted through the Google Scholar and Crossref database with the assistance of the Publish or Perish application using the keywords "spatial ability," "mathematics learning," and "GeoGebra" within the 2020–2025 publication period. The initial search identified 200 articles. Subsequently, the articles were screened based on the established inclusion and exclusion criteria through title screening, abstract screening, and similarity checking. After the selection process, 12 journal articles met the criteria and were included in this study. Furthermore, the selected articles were classified according to the authors and year of publication, publisher, learning model, participants, and research findings related to students' spatial abilities in GeoGebra-assisted mathematics learning. The classification of the selected studies is presented in Table 2.

Table 2. Classification and Research Findings of Selected Literature

Author and Year of Publication	Publisher	Learning Model	Participants	Research Result
Rahmawati, S., Syofra, A. H., & Saragih, S. R. D. (2021).	JEMS (Jurnal Edukasi Matematika dan Sains)	-	High School Students	The study showed that students who participated in GeoGebra-assisted mathematics learning achieved better spatial ability performance compared to conventional learning.
Rahman, T., & Saputra, J. (2022).	Symmetry: Pasundan Journal of Research in Mathematics Learning and Education	Discovery Learning	Vocational School Students	The findings indicated that students' mathematical spatial abilities improved after the implementation of guided discovery learning assisted by GeoGebra, particularly in solving spatial visualization problems.
Sari, H. A., Susanto, S., &	AKSIOMA: Jurnal Program	Problem-Based	Elementary School	Problem-based learning supported by GeoGebra

Yudianto, E. (2022).	Studi Pendidikan Matematika	Learning	Students	significantly improved students' spatial abilities based on the results of learning outcome assessments and spatial ability tests.
Suryati, K., & Adnyana, I. G. (2022).	PENDIPA Journal of Science Education	Realistic Mathematics Education (RME)	Junior High School Students	The study found an interaction between realistic mathematics education assisted by GeoGebra and students' spatial abilities toward geometry learning outcomes.
Simamora, D. K., Maria, N. S., Adhawina, R., Manik, R. S., Khafifah, S., & Siregar, B. H. (2024).	JagoMIPA: Jurnal Pendidikan Matematika dan IPA	Realistic Mathematics Education (RME)	Junior High School Students	The implementation of RME assisted by GeoGebra resulted in higher spatial ability achievement on cube and cuboid materials among junior high school students.
Febrianti, D. A., Tambunan, E. E. B., Tarigan, G. H., Lestari, J. A., Tampubolon, S. T. V., & Siregar, B. H. (2024).	JagoMIPA: Jurnal Pendidikan Matematika dan IPA	Realistic Mathematics Education (RME)	Junior High School Students	The findings revealed that Realistic Mathematics Education (RME) assisted by GeoGebra significantly enhanced students' spatial abilities during mathematics learning activities.
Nurafifah, L., Wati, M., & Mellawaty, M. (2024).	Kognitif: Jurnal Riset HOTS Pendidikan Matematika	-	Junior High School Students	Students who learned mathematics using GeoGebra demonstrated better spatial ability performance and understanding of geometric concepts.
Kirana, R., Hidayah, I., & Suyitno, A. (2024).	Jurnal Cendekia: Jurnal Pendidikan Matematika	Van Hiele	Junior High School Students	The Van Hiele learning model assisted by the virtual media GeoGebra was found to effectively improve students' spatial abilities in geometry learning.
Wardini, S. G., Kadir, K., & Dimyati, A. (2024).	ALGORITMA: Journal of Mathematics Education, 6(2), 135-150.	Discovery Learning	Junior High School Students	Discovery Learning assisted by GeoGebra positively influenced students' spatial abilities based on the comparison of learning outcomes before and after the intervention.
Nurjanah, T., Rahayu, D. V., & Heryani, Y. (2025).	Jurnal Inovasi Pembelajaran Matematika: PowerMath Edu (PME)	Project-Based Learning	High School Students	The Project Based Learning model assisted by GeoGebra showed a positive effect on students' spatial abilities, especially in understanding three-dimensional concepts.
Luritawaty, I. P., & Sumartini, T. S. (2025).	Ar-Riyadhiyyat: Journal of Mathematics Education	Problem-Based Learning	Junior High School Students	The PBL-based GeoGebra e-module improved junior high school students' mathematical spatial abilities on solid geometry material through interactive visualization features.
Maria, N. S.,	PESHUM:	Realistic	Junior High	The findings demonstrated that

Khafifah, S., Saragih, A. G., Wardana, A., Sagala, P. N., & Manik, R. S. (2025).	Jurnal Pendidikan, Sosial dan Humaniora,	Mathematics Education (RME)	School Students	the RME approach assisted by GeoGebra had a positive impact on students' spatial abilities and geometry learning performance.

(RQ1) What are the research trends in 2020-2025 regarding students' spatial abilities in GeoGebra-assisted mathematics learning?

Bibliometric analysis was conducted using VOSviewer. The data obtained from Publish or Perish were exported in RIS format and analyzed using the co-occurrence analysis feature with keywords as the unit of analysis. The analysis applied the full counting method to generate network visualization and overlay visualization in order to identify the relationships and research trends related to spatial ability in GeoGebra-assisted mathematics learning.

Figure 2 presents the distribution of articles by year of publication. This visualization was used to identify research trends related to students' spatial abilities in GeoGebra-assisted mathematics learning during the 2020–2025 period.

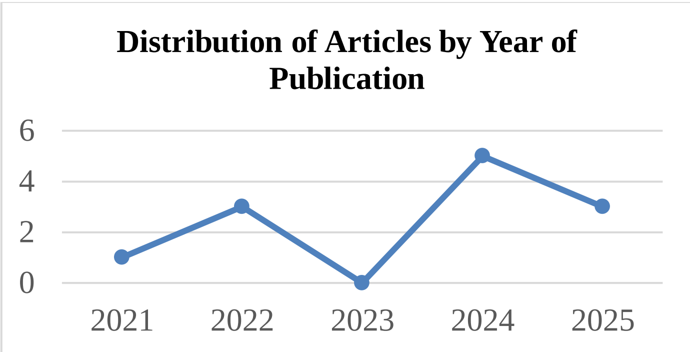


Figure 2. Distribution of Articles Based by Year of Publication

Based on Figure 2, the distribution of articles related to students' spatial abilities in GeoGebra-assisted mathematics learning showed fluctuations during the 2021–2025 period. The number of publications increased from 2021 to 2022, decreased in 2023, and reached its highest point in 2024 before declining again in 2025. The findings indicate that research on the integration of GeoGebra in mathematics learning to support students' spatial abilities has attracted considerable attention from researchers during the observed period.

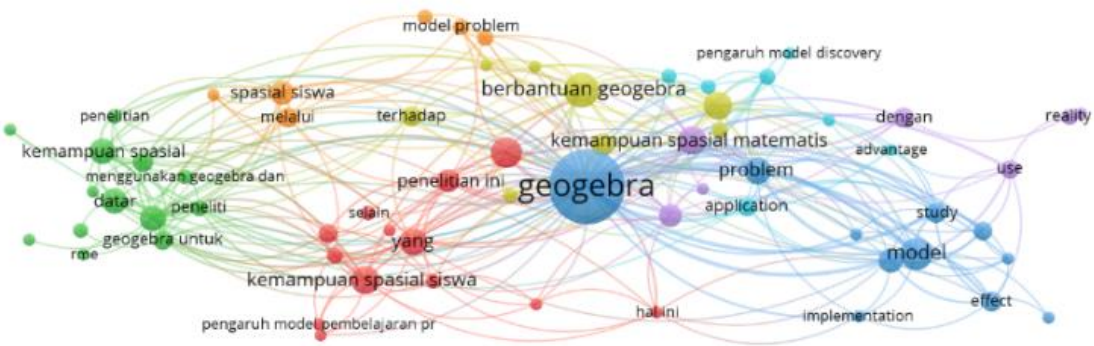


Figure 3. Visualization of the Relationship Between Keywords

Based on the network visualization results in Figure 3, the relationships between keywords frequently appearing in research related to students' spatial abilities in GeoGebra-assisted mathematics learning are evident. The visualization shows seven clusters marked with different colors. The size of the circle around each keyword indicates the frequency of occurrence; the larger the circle, the more discussion of that keyword. Meanwhile, the connecting lines between the circles indicate the relationship or connection between one keyword and another. The keywords "GeoGebra" and "Spatial Ability" dominate the network, indicating that much research focuses on efforts to improve spatial abilities through GeoGebra-assisted mathematics learning. The relationship between the keywords "problem," "discovery," and "model" also confirms that these studies examine the application of GeoGebra in various learning models, such as problem-based learning and discovery learning, which are oriented towards improving students' spatial abilities.

Visualization of the relationship between keywords shows that research on GeoGebra does not only focus on its use as a technological tool, but also on its role in supporting innovative learning models such as problem-based learning, discovery learning, and realistic mathematics education to improve spatial abilities in mathematics learning.

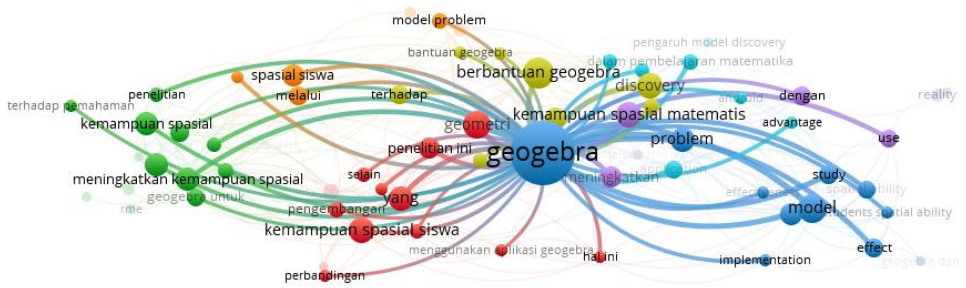


Figure 4. Keyword Relationships

According to figure 4, the results of the keyword relationship analysis show that the term "GeoGebra" occupies a central position in the network with the strongest connections to various other keywords. The keyword "GeoGebra" is closely connected to the keyword "spatial ability," indicating that most research focuses on the use of GeoGebra as an interactive learning medium to improve students' spatial abilities. This connection indicates that GeoGebra is seen as an effective digital tool in supporting the visualization of mathematical concepts, especially in geometry and spatial representation materials. In addition, the strong connection between "GeoGebra" and the keywords "learning model," "problem," and "discovery" shows that much research is directed at the application of GeoGebra in various innovative learning models, such as problem-based learning and discovery learning. This connection confirms that the use of GeoGebra is not only limited to teaching aids, but also becomes an integral part of learning strategies that emphasize the development of students' spatial abilities. Other keywords such as “student spatial,” “influence of discovery models,” and “problem models” enrich the network of relationships, indicating that studies on GeoGebra extend to the impact of implementing learning models on improving students’ mathematical spatial abilities. The connection with the keywords “implementation,” “effect,” and “advantage” also shows that these studies not only discuss the theory of GeoGebra application but also highlight the impact and effectiveness of its use in terms of real-life learning. Overall, this keyword network map confirms that GeoGebra serves as a central axis in current research related to the development of spatial abilities and the implementation of technology-integrated learning models. These findings illustrate an increasingly strong research direction in utilizing GeoGebra as an innovative learning medium capable of supporting the mastery of mathematical concepts while improving students’ spatial skills in the era of 21st-century mathematics learning.

Research trends for 2020–2025 related to the use of GeoGebra in developing students' spatial abilities are shown in Figure 5 below through the color differences in each circle. Lighter colors indicate more recent research, while darker colors indicate research conducted in previous years. This color pattern provides an overview of the development of research focus over time, thus identifying the direction of studies on GeoGebra-assisted mathematics learning in improving students' spatial abilities.

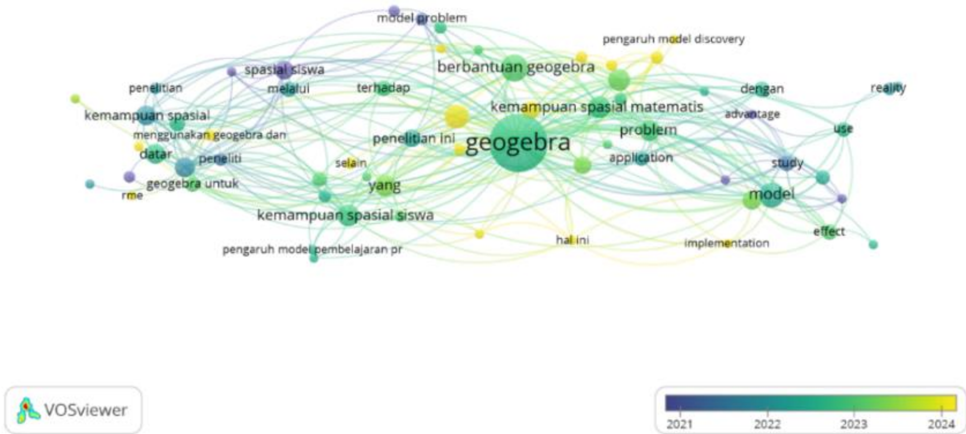


Figure 5. Overlay Visualization

The overlay visualization results in Figure 5 show that research trends are evolving dynamically in line with the use of GeoGebra, which is not only focused on its use as a visualization tool but also increasingly moving towards its use in developing students' spatial abilities. In the blue circles, the research focus remains on the use of GeoGebra in mathematics learning to improve spatial abilities. Keywords such as "spatial ability" and "application" dominate, indicating that at this stage GeoGebra is primarily used as a visualization tool for mathematical concepts. Furthermore, in the green circles, a shift in research direction is evident, toward topics that are more integrated with learning models. The interrelationship of keywords such as “GeoGebra-assisted,” “problem,” and “model” indicates that research is beginning to focus on implementing GeoGebra in innovative learning models such as problem-based learning. At this stage, GeoGebra is not only viewed as a technological tool, but also as an important component in improving students’ spatial abilities. Then, in the yellow circle, research trends increasingly emphasize integrative and applicative aspects. New keywords such as “the influence of the discovery model,” “rme,” and “implementation” are starting to appear, indicating that recent studies are placing more emphasis on integrating GeoGebra with more innovative learning models such as discovery learning and realistic mathematics education to improve spatial abilities in mathematics learning. Thus, based on the results of the overlay visualization, it can be concluded that the research trend regarding spatial abilities in GeoGebra-assisted mathematics learning continues to develop over time, starting from the initial stage as a medium to help visualize concepts, to the stage of application in innovative learning models, and finally becoming a contextual learning strategy that emphasizes strengthening spatial abilities in the digital era. These findings indicate that topics related to the application of GeoGebra to students' spatial abilities have increasing relevance and novelty along with the development of 21st century learning.

(RQ2) How are Students' Spatial Abilities in GeoGebra-Assisted Mathematics Learning?

Students' spatial abilities in GeoGebra-assisted mathematics learning were analyzed based on 12 research articles that met the inclusion and exclusion criteria. The analysis was conducted by classifying the articles into two main aspects: (1) learning model; (2) educational level.

Based on the results of a literature review, various learning models integrated with GeoGebra in mathematics lessons have demonstrated significant effectiveness in improving students' spatial abilities. The learning models most frequently encountered in research include Discovery Learning, Problem-Based Learning (PBL), Project-Based Learning (PjBL), Realistic Mathematics Education (RME), and Van Hiele. Each model has characteristics and advantages that contribute to improving students' spatial abilities through an interactive and visual technology-based approach. The following distribution of the use of learning models that can improve spatial abilities can be seen in Figure 6.

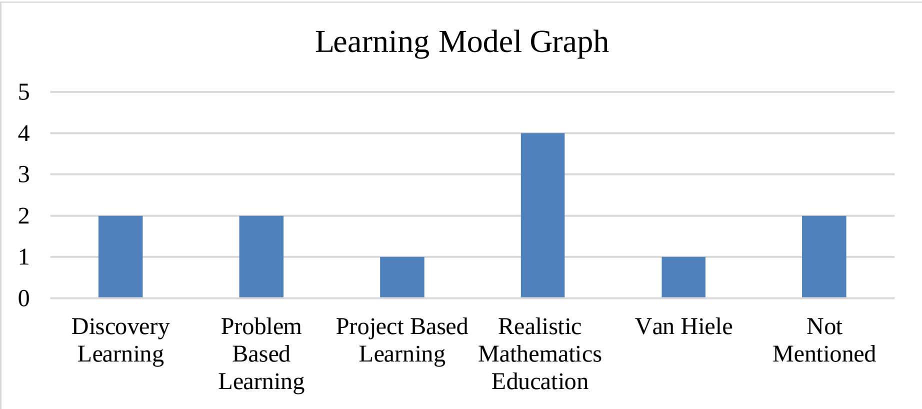


Figure 6. Learning Model Graph

The GeoGebra-assisted Discovery Learning model has a positive impact on students' spatial abilities (Wardini et al., 2024). Through this model, students are guided to discover mathematical concepts themselves with the help of GeoGebra visualizations. This model provides space for students to explore, observe, and draw conclusions independently, thus enhancing their understanding of geometric concepts. This aligns with the findings of Rahman & Saputra (2022) that guided discovery learning with GeoGebra can increase student engagement and reasoning activities in understanding spatial concepts.

The Problem-Based Learning model is also widely used in integrating GeoGebra. Sari et al. (2022) and Luritawaty & Sumartini (2025) stated that the use of GeoGebra-assisted problem-based learning tools helps students visualize problems in concrete forms, making it easier for them to find solutions through direct exploration and manipulation of geometric objects. The GeoGebra-integrated Problem-Based Learning model used in learning can increase learning motivation, thus improving students' spatial abilities. Furthermore, the use of technology in mathematics learning not only improves students' understanding and skills but also encourages teachers to be more innovative in delivering material.

The GeoGebra-assisted Project-Based Learning model also has a positive impact on spatial abilities. Based on research by Nurjanah et al. (2025), the implementation of the GeoGebra-assisted Project-Based Learning model can create a collaborative and project-oriented learning environment, enabling students to apply mathematical concepts to contextual situations. This not only improves conceptual understanding but also strengthens students' spatial analysis skills.

The Realistic Mathematics Education (RME) approach with the help of GeoGebra is one of the learning innovations that has consistently shown positive results on students' spatial abilities. Several studies by Suryati & Adnyana (2022), Simamora et al. (2024), Febrianti et al. (2024), and Maria et al. (2025) confirmed that learning with the RME approach facilitates students to build mathematical concepts through realistic and meaningful situations, while GeoGebra strengthens visual exploration so that the process of discovering concepts becomes easier to understand. This learning also encourages students to think reflectively, creatively, and systematically in understanding the relationships between geometric objects. Mathematics learning that integrates the Realistic Mathematics Education (RME) approach with the help of GeoGebra can be implemented as an effective strategy to improve and strengthen students' spatial understanding.

The Van Hiele model integrated with GeoGebra also plays a crucial role in enhancing spatial understanding. Research by Kirana et al. (2024) shows that the Van Hiele model, aided by the virtual media GeoGebra, is effective in helping students move from the visualization stage to the analytical stage. GeoGebra helps accelerate the transition between Van Hiele levels of thinking because it allows students to directly see the relationships between shapes through digital simulations and manipulation. This model can be implemented as an alternative learning method because it facilitates the gradual geometric thinking process through visualization and direct interaction with geometric objects.

Mathematics learning involving GeoGebra provides a more interactive and meaningful learning experience. Students not only passively receive information but also actively engage in exploring, observing, and directly manipulating geometric objects. This activity encourages independent concept discovery, supporting the development of visualization, perception, orientation, relationships, and spatial rotation skills. Furthermore, with the help of digital visualization, students can more easily understand the relationships between shapes, see differences in spatial transformations, and connect abstract representations to more concrete forms.

The use of GeoGebra in various learning models also demonstrates the critical role of technology in creating learning that is more adaptive to 21st-century needs. Teachers can design more varied and contextual activities, while students gain learning experiences that align with visual and exploratory learning styles. This demonstrates a positive relationship between the application of learning technology and improved spatial thinking and understanding of mathematical concepts.

Mathematics learning through GeoGebra-assisted learning models demonstrates improvements in students' spatial abilities. The use of GeoGebra not only supports the success of various innovative learning models but also has the potential to strengthen mathematics learning to make it more interactive, contextual, and relevant to current technological developments. Integrating appropriate learning models and the use of GeoGebra is a strategic alternative for developing higher-order thinking skills, particularly in spatial and geometric aspects.

The distribution of educational levels in studies related to students' spatial abilities in GeoGebra-assisted mathematics learning shows quite interesting variation and provides insight into how this technology is applied at various levels of education. Based on a review of the 12 articles analyzed, all studies fall into the empirical research category, meaning they directly involve students in the GeoGebra-assisted learning process. This indicates that the use of GeoGebra is not only studied theoretically but has been extensively tested in mathematics learning practices to determine its impact on students' spatial abilities.

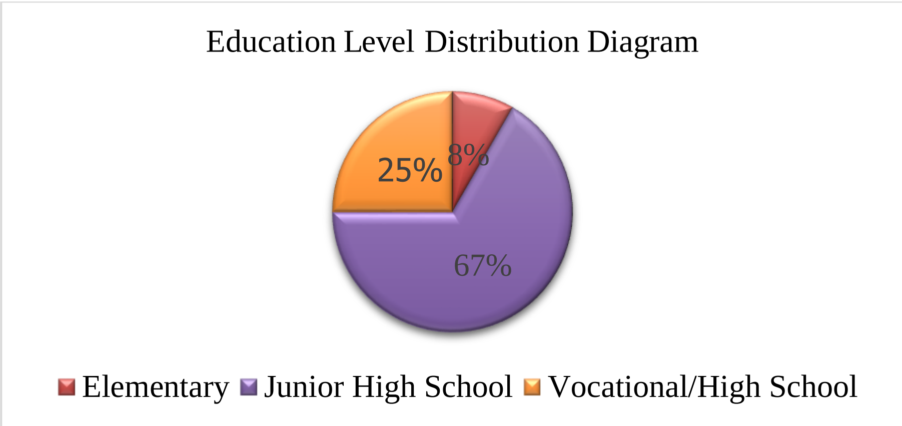


Figure 7. Education Level

Based on Figure 7, the distribution of educational levels shows that the most research was conducted at the junior high school level, with approximately 67% of the research. This dominance at this level indicates that junior high school is considered a crucial phase in the development of students' spatial abilities. At this age, students begin to shift from concrete to abstract thinking, making GeoGebra's visualizations highly effective in bridging their understanding of geometric concepts. The use of GeoGebra also helps enhance students' interaction with geometric objects through hands-on exploration, positively impacting spatial understanding. Meanwhile, at the senior high school/vocational school level, it accounts for around 25%. Research at this level generally utilizes learning models integrated with GeoGebra to deepen understanding of more complex geometric concepts. Students at the senior high school level already possess more mature formal thinking skills, so the use of GeoGebra plays a role in strengthening spatial abilities, problem-solving, and logical reasoning. Research in vocational schools generally focuses on the application of GeoGebra in more practical and applied learning, for example, to support skills in engineering, design, or other vocational fields that require advanced visualization. This demonstrates that GeoGebra is not only effective in the academic realm but is also relevant in vocational education, which emphasizes the direct application of mathematical concepts. Although the number of studies in senior high schools is not as high as in junior high schools, the results indicate that GeoGebra integration remains relevant and effective for improving spatial abilities at higher levels of education. Research involving elementary school students accounts for 8% of the research, emphasizing the use of GeoGebra to visually introduce basic geometric concepts and spatial forms. Although limited, the use of GeoGebra in elementary schools has been shown to help students understand simple spatial relationships, such as position, shape, and size, through interactive learning activities. This demonstrates significant potential for further research at the elementary school level, enabling students to build a foundation of spatial skills from an early age.

Junior high school students are the most dominant group in research on GeoGebra-assisted learning for improving spatial skills, followed by senior high school/vocational high school and elementary school. These findings suggest that the junior high school phase is the most strategic stage for instilling spatial skills through technology-based media. The limited number of studies at the senior high school/vocational high school and elementary school levels opens up significant opportunities for further research to explore the effectiveness of GeoGebra at both levels. Therefore, the results of this analysis confirm that GeoGebra-assisted mathematics learning is highly flexible and adaptable across various educational levels.

CONCLUSION AND SUGGESTION

Based on the analysis and discussion, several conclusions can be drawn. First, research trends on spatial abilities in GeoGebra-assisted mathematics learning show progressive development over time. GeoGebra, which was initially used as a medium to visualize geometric concepts, was later applied in various innovative learning models, and now plays a role as a contextual learning strategy that emphasizes strengthening spatial abilities in the digital era. This shows that the application of GeoGebra in developing spatial abilities is not only pedagogically relevant but also presents important novelties in supporting 21st-century mathematics learning. Second, GeoGebra-assisted mathematics learning has proven effective in improving students' spatial abilities at various levels of education. Various learning models such as Realistic Mathematics Education (RME), Problem-Based Learning (PBL), Project-Based Learning (PjBL), Van Hiele, and Discovery Learning are able to facilitate the visualization, manipulation, and analysis of geometric objects interactively, so that students can understand abstract concepts more concretely. In terms of educational level, most research has been conducted in junior high schools, followed by senior high schools/vocational schools, and a small number in elementary schools. GeoGebra is most often applied in the transition phase from concrete to formal thinking, but remains relevant for strengthening spatial analysis skills at higher levels and building spatial foundations at the elementary level. Thus, GeoGebra is flexible and effective for integration with various innovative learning models to support the development of students' spatial abilities.

Future research could expand the scope to elementary and tertiary levels to obtain a more comprehensive picture of GeoGebra's effectiveness. Furthermore, developing a learning model that integrates GeoGebra with other digital technologies, such as augmented reality, could be an innovative alternative to further enhance students' spatial abilities. This integration is expected to not only strengthen conceptual understanding but also support students' readiness to face the challenges of learning mathematics in the digital age.

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