Spatial Ability in Mathematics Learning: A Systematic Review from the Perspective of Technology and Learning Models

Zulfa Dayyinati Fa'izulloh[1*)], Bambang Eko Susilo[2], Arief Agoestanto[3], Scolastika Mariani[4]
[1,2,3,4]Universitas Negeri Semarang
*) zulfadayyinati@students.unnes.ac.id

Abstract

This study aims to examine the role of technology and learning models in improving students' spatial abilities in mathematics learning. Using the Systematic Literature Review (SLR) method guided by the PRISMA framework, this study analyzed seven relevant articles published between 2020 and 2025 from reputable databases such as Google Scholar, Semantic Scholar, and SINTA. The findings indicate that various learning technologies, including GeoGebra, Augmented Reality (AR), Virtual Reality–based mobile learning, Math City Maps, and Adobe Flash, have a positive impact on supporting visualization, interaction, and students' understanding of geometric and spatial concepts. In addition, constructivist-oriented learning models such as Problem Based Learning (PBL), Guided Discovery Learning, Contextual Teaching and Learning (CTL), the Van Hiele model, and Thinking Aloud Pair Problem Solving (TAPPS) provide more meaningful learning experiences by encouraging active exploration, discussion, and independent construction of spatial concepts. The results further demonstrate that the integration of interactive and immersive technologies with appropriate learning models produces a synergistic effect in enhancing students' mathematical spatial abilities. These findings offer an important foundation for educators in designing mathematics instruction that is more innovative, contextual, and aligned with the characteristics of the digital generation. Future research is recommended to further investigate the effectiveness of specific combinations of technologies and learning models in authentic classroom settings

Keywords: Spatial ability, Technology, Learning Model, Mathematics Learning.

Introduction

Spatial ability is a crucial cognitive skill in mathematics learning, particularly geometry. This is because it involves understanding and manipulating objects in space, as well as the ability to visualize and imagine these objects from various perspectives (Daryati et al., 2024). Good spatial ability enables students to understand geometric concepts, such as geometric shapes, size, position, and the relationships between objects in space (Siyam et al., 2024). Therefore, spatial ability is an important aspect of mathematics that students must master to solve geometric problems and other mathematical problems effectively.

In reality, many students have difficulty understanding geometric concepts, which is largely due to their low spatial abilities or spatial abilities (Sudirman & Alghadari, 2020). This is confirmed by research conducted by Darmawan et al., (2019), many students have difficulty visualizing three dimensional objects in two-dimensional images, as well as in understanding spatial relationships or relations between the objects in question. This indicates that learning mathematics, especially geometry, requires appropriate learning technology and can improve students' spatial abilities.

The development of students' spatial abilities not only impacts their geometric understanding, but also impacts their critical and creative thinking skills in solving mathematical problems. As research by Prawita et al., (2024), manipulative and model-based interventions in learning spatial geometry help students develop a more concrete understanding of spatial and geometric concepts, which in turn contributes to the improvement of their critical and creative thinking skills. In today's dynamic and fast-changing global context, spatial thinking has become an essential competence across various disciplines, including architecture, engineering, science, and art (Wijayanto et al., 2020). Therefore, spatial abilities are not only useful in academic contexts, but also in everyday life and the professional world.

Based on this, the development of spatial abilities needs to be positioned as a core component of mathematics learning, as many students still experience difficulties in visualizing and understanding geometric concepts when instruction relies solely on abstract and symbolic representations. In response to this challenge, various instructional approaches have been developed to enhance students' spatial abilities, particularly through interactive and technology supported learning models. Several studies have employed technology supported learning models with varying focuses and outcomes. For example, Nurwijaya, (2022) demonstrated that Problem Based Learning supported by Augmented Reality effectively improves students' ability to visualize and manipulate three dimensional objects through contextual problem solving activities. Other studies have emphasized guided discovery approaches supported by dynamic software such as GeoGebra, highlighting their effectiveness in facilitating students' exploration of geometric relationships through visual experimentation. In addition, contextual approaches using real world applications, such as Math City Maps, have been shown to strengthen students' spatial understanding by connecting mathematical concepts with authentic spatial environments.

Although these findings are promising, previous studies tend to focus on specific technologies or individual learning models in isolation, with limited discussion on how different approaches can be compared or complement one another. As a result, there remains a gap in comprehensive understanding regarding the most effective combinations of technologies and learning models for supporting students' spatial abilities across various learning contexts. Therefore, this study employs a Systematic Literature Review (SLR) approach to systematically map, compare, and synthesize previous research related to technology assisted learning models in the development of mathematical spatial ability. Through this approach, the study aims to identify research trends, strengths, and gaps, thereby providing a clearer framework for educators in selecting and integrating appropriate technologies and learning models to enhance students' spatial abilities.

The importance of spatial ability is also reflected in numerous studies indicating that students with well-developed spatial skills tend to demonstrate stronger understanding of geometry and greater competence in solving a wide range of mathematical problems (Oktaviana, 2016). However, previous research has employed diverse technologies and learning models with varying focuses and outcomes, and most studies have examined these approaches in isolation rather than providing a comprehensive comparison or synthesis. In response to this gap, the present study aims to systematically examine the role of technology and learning models in enhancing students' spatial abilities in mathematics learning. Specifically, this study seeks to address the following research questions: (RQ1) What is the role of technology in improving students' spatial abilities in mathematics learning? and (RQ2) How do learning models influence the improvement of students' spatial abilities in mathematics learning? To answer these questions in a comprehensive and evidence-based manner, this study employs a Systematic Literature Review (SLR) approach.

Method

This study employs a Systematic Literature Review (SLR) method using the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta Analyses) framework to ensure a transparent, systematic, and replicable review process (Triandini et al., 2019). The PRISMA approach was selected because it provides a clear procedural structure for identifying, screening, and synthesizing relevant studies. The review process was conducted through four main stages: (1) the identification stage**,** which involved identifying relevant articles through searches of the Google Scholar, Semantic Scholar, and SINTA databases using predefined keywords related to spatial ability, mathematics learning, technology, and learning models; (2) the screening stage**,** in which articles were screened based on predetermined inclusion and exclusion criteria; (3) the eligibility stage**,** which involved assessing the quality of the selected articles; and (4) the included stage**,** which consisted of data extraction and synthesis to address the research questions. This structured process ensured that only relevant and high-quality studies were included in the final analysis. The inclusion and exclusion criteria applied in this study are presented in Table 1 below.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Articles relevant to the use of technology and learning models in improving spatial abilities in mathematics learning	Articles that are not relevant to improving spatial abilities in mathematics learning
Articles published between 2020 and 2025	Articles published before 2020
Articles obtained from reputable academic databases indexed in SINTA 1–4 or Scopus	Articles obtained from unverified sources or indexed outside SINTA 1–4 or Scopus

The final stage of the review process was the quality assessment. After the relevant articles had been selected, their quality was evaluated using the following criteria: (QA1) whether the article discusses the use of technology in mathematics learning to improve students' spatial abilities; (QA2) whether the article explains the learning model used to enhance students' spatial abilities in mathematics learning; and (QA3) whether the article reports the results or impacts of the application of technology or learning models on students' spatial abilities. This assessment ensured that only studies meeting the established quality standards were included in this SLR. The overall article selection process is illustrated in the PRISMA flow diagram shown in Figure 1, which provides a clear overview of the identification, screening, eligibility, and inclusion stages.

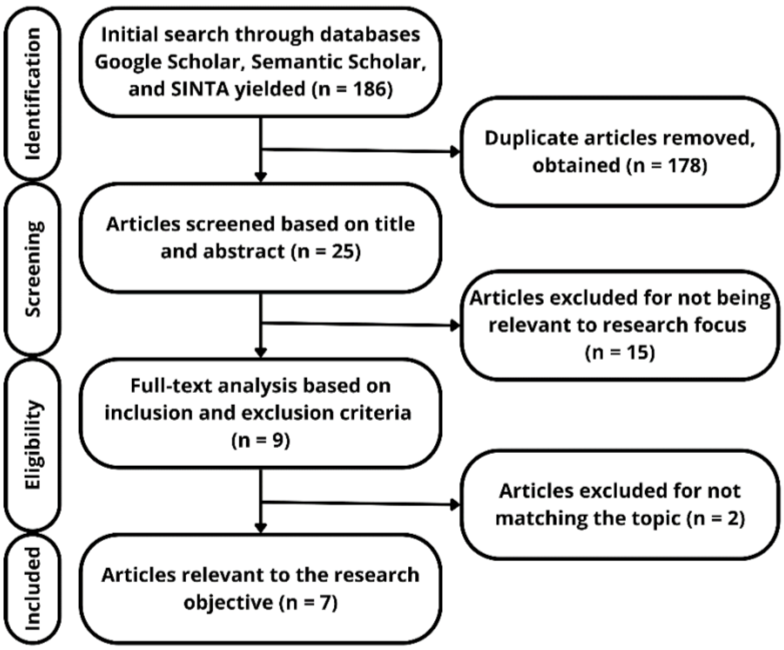

Figure 1. Search Strategy Using PRISMA 2020

As shown in Figure 1, the initial database search in Google Scholar, Semantic Scholar, and SINTA yielded 186 articles relevant to the research keywords. After duplicate records were removed, 178 articles remained for title and abstract screening. During this stage, 153 articles were excluded because they were not aligned with the research focus on spatial ability, mathematics learning, or the use of technology and learning models. Consequently, 25 articles proceeded to further analysis. At the eligibility stage, 9 articles were assessed in full text, of which 7 articles met the research objectives and inclusion criteria. These articles were subsequently selected and analyzed in-depth in this systematic literature review.

Results and Discussion

Based on the PRISMA 2020 guided selection process, seven articles met the inclusion and quality assessment criteria and were included in this systematic literature review. These studies were identified as the most representative because they explicitly examined both the use of technology and the application of learning models in improving students' spatial abilities in mathematics learning. The seven studies were used as illustrative core studies, while the remaining articles contributed to a broader thematic synthesis addressing the two research questions.

RQ1: The Role of Technology in Improving Students' Spatial Abilities

Table 2 summarizes representative studies addressing RQ1, focusing on the types of technology employed and their reported impacts on students' spatial abilities.

Table 2. Studies Addressing RQ1: The Role of Technology in Improving Students' Spatial Abilities

Author (Year)	Technology Used	Learning Context	Main Findings Related to Spatial Ability
Nurwijaya, (2022)	Augmented Reality (AR)	Geometry (3D shapes)	AR enhances students' ability to visualize and manipulate three-dimensional objects, particularly when combined with contextual problem-solving tasks.
Mardhatillah et al., (2022)	Adobe Flash	Spatial geometry	Visual animations support students' understanding of spatial relationships and improve spatial visualization skills.
Rahman & Saputra, (2022)	GeoGebra	Geometry concepts	Dynamic visualization through GeoGebra facilitates students' exploration of geometric transformations and spatial relationships.

Nurhaliza & Widyasari, (2024)	Math City Maps	Real-world spatial tasks	Location-based technology strengthens students' spatial awareness by connecting geometry with authentic environments.
Kirana et al., (2024)	GeoGebra-based virtual media	Geometry learning	Virtual manipulation of geometric objects supports higher levels of spatial reasoning and visualization.
Pitriyani et al., (2025)	GeoGebra-based e-module	Solid geometry	Interactive digital modules significantly improve students' spatial visualization and understanding of spatial structures.
Sugiarto et al., (2023)	Mobile learning based on Virtual Reality	Flat-sided solid geometry (junior high school)	VR-based mobile learning media were proven to be valid, practical, and effective in improving students' spatial abilities, as indicated by learning mastery ≥75%, t-test results, and a moderate N-Gain improvement.

The findings consistently indicate that visual, interactive, and immersive technologies play a crucial role in enhancing students' spatial abilities in mathematics learning. Technologies such as Augmented Reality, GeoGebra, Adobe Flash, Math City Maps, and Virtual Reality-based mobile learning enable students to visualize, manipulate, and explore geometric objects that are otherwise abstract when presented through conventional instruction.

For instance, Nurwijaya, (2022) demonstrated that Augmented Reality functions as a visual gateway that transforms abstract three dimensional concepts into more concrete representations. When integrated with Problem Based Learning, AR does not merely serve as a visualization tool but actively supports students in solving contextual problems, thereby strengthening mental rotation, spatial visualization, and spatial relationship skills. In a more immersive approach, Sugiarto et al., (2023) showed that Virtual Reality based mobile learning provides a simulated three dimensional environment that allows students to interact directly with geometric objects. This immersive interaction significantly improves students' spatial abilities, as evidenced by learning mastery, comparative learning outcomes, and moderate N-Gain improvement.

Similarly, Rahman & Saputra, (2022) found that GeoGebra facilitates dynamic exploration of geometric objects, enabling students to rotate, decompose, and reconstruct shapes virtually. Such interactive engagement supports the gradual construction of spatial understanding through exploration rather than direct explanation. Adobe Flash based animations also contribute to spatial learning by supporting students' understanding of spatial relationships through clear visual representations (Mardhatillah et al., 2022). In a different context, Math City Maps extends spatial learning beyond the classroom by situating geometry within real world environments, allowing students to interpret spatial relationships authentically (Nurhaliza & Widyasari, 2024).

Overall, the reviewed studies confirm that technology enhances students' spatial abilities primarily by providing dynamic and immersive visual representations, supporting the manipulation of geometric objects, and bridging abstract mathematical concepts with concrete and contextual learning experiences.

RQ2: The Influence of Learning Models on Students' Spatial Abilities

Table 3. Studies Addressing RQ2: The Influence of Learning Models on Students' Spatial Abilities

Author (Year)	Learning Model	Instructional Characteristics	Contribution to Spatial Ability
Nurwijaya, (2022)	Problem Based Learning (PBL)	Contextual problem solving	Encourages students to construct spatial understanding through real world problem situations.
Mardhatillah et al., (2022)	Thinking Aloud Pair Problem Solving (TAPPS)	Verbalization and peer interaction	Enhances metacognitive awareness and spatial reasoning through reflective dialogue.
Rahman & Saputra, (2022)	Guided Discovery Learning	Teacher guided exploration	Supports gradual development of spatial concepts through exploration rather than direct instruction.
Nurhaliza & Widyasari, (2024)	Contextual Teaching and Learning (CTL)	Learning based on real contexts	Strengthens spatial understanding by linking mathematical concepts to real life spatial situations.
Kirana et al., (2024)	Van Hiele Model	Hierarchical geometric thinking levels	Facilitates progression from visualization to formal reasoning in geometry learning.
Pitriyani et al., (2025)	Problem Based Learning (PBL)	Student centered problem solving	Promotes deeper spatial conceptualization and independent learning supported by digital resources.
Sugiarto et al., (2023)	Problem Based Learning integrated with Mobile Learning (VR-based)	Student centered learning supported by immersive virtual environments	Improves students' spatial visualization, mental rotation, and spatial relations through immersive exploration of three dimensional objects; supports significant gains in spatial ability (N-Gain: moderate).

Table 3 presents the learning models employed in the reviewed studies and highlights how each model contributes to the development of students' spatial abilities.

Regarding learning models, the findings reveal that constructivist oriented models are particularly effective in supporting the development of students' spatial abilities. Learning models such as Problem Based Learning (PBL), Guided Discovery Learning, Contextual Teaching and Learning (CTL), the Van Hiele model, and Thinking Aloud Pair Problem Solving (TAPPS) emphasize active learning, exploration, and deep cognitive engagement in constructing spatial understanding.

Problem Based Learning (PBL) emerged as the most frequently applied instructional model across the reviewed studies. Research by Nurwijaya, (2022) and Pitriyani et al., (2025) demonstrates that PBL encourages students to develop spatial understanding through contextual problem solving activities rather than rote memorization. Moreover, recent findings by Sugiarto et al., (2023) indicate that when PBL is integrated with immersive technologies such as Virtual Reality based mobile learning, students are able to interact directly with three dimensional geometric environments. This integration enhances spatial visualization, mental rotation, and spatial relationships, leading to more meaningful and sustained conceptual understanding.

The Van Hiele model, as reported by Kirana et al., (2024), provides a structured progression of geometric thinking from visualization to formal deduction. The incorporation of virtual media facilitates students' movement across these levels by enabling direct manipulation, comparison, and exploration of geometric properties. In addition, Thinking Aloud Pair Problem Solving (TAPPS) promotes metacognitive awareness by encouraging students to verbalize their spatial reasoning processes, which strengthens both spatial understanding and mathematical resilience (Mardhatillah et al., 2022).

Overall, these findings indicate that learning models influence the development of spatial abilities by structuring cognitive processes, fostering exploration and reflection, and supporting collaborative problem solving. These effects become more pronounced when learning models are integrated with appropriate technological tools, particularly interactive and immersive technologies that enhance students' engagement with spatial representations.

Synthesis of RQ1 and RQ2

Synthesizing the findings from both research questions, it is evident that technology and learning models are most effective when they are integrated rather than applied independently. Technology provides essential visual, interactive, and manipulative affordances that support spatial learning, while learning models structure students' cognitive engagement, exploration, and meaning making processes.

Across the reviewed studies, GeoGebra emerges as the most frequently utilized technology due to its flexibility and dynamic visualization capabilities, particularly in geometry learning. At the same time, emerging immersive technologies such as Virtual Reality and Augmented Reality demonstrate strong potential in further enhancing students' spatial abilities by enabling direct interaction with three dimensional environments. Regarding instructional approaches, Problem Based Learning stands out as the most commonly applied learning model because of its effectiveness in contextualizing spatial problems, promoting higher order thinking skills, and supporting student centered exploration. When integrated with interactive and immersive technologies, such as GeoGebra, AR, or VR based mobile learning, PBL creates learning experiences that are both meaningful and cognitively engaging.

In conclusion, mathematics learning that integrates interactive and immersive technologies with constructivist oriented learning models provides a more effective and comprehensive environment for developing students' spatial abilities. Such integration not only enhances spatial visualization but also strengthens conceptual understanding, critical thinking, and sustainable problem solving skills, thereby offering a robust framework for mathematics education in the digital era.

Conclusion and Suggestions

This systematic literature review of seven selected studies published between 2020 and 2025 demonstrates that the integration of learning technology with constructivist oriented learning models plays a significant role in enhancing students' spatial abilities in mathematics learning. The reviewed studies consistently show that technologies such as GeoGebra, Augmented Reality, Virtual Reality based mobile learning, Adobe Flash, and Math City Maps effectively support students in visualizing abstract geometric concepts, manipulating three-dimensional objects, and developing stronger spatial mental representations.

In addition, learning models including Problem Based Learning, Guided Discovery Learning, Thinking Aloud Pair Problem Solving, Contextual Teaching and Learning, and the Van Hiele model were found to be effective in fostering active engagement, exploration, and deeper spatial understanding. Among these, Problem Based Learning emerged as the most frequently applied model, particularly when integrated with interactive and immersive technologies. The findings clearly indicate that improvements in students' spatial abilities are more substantial when technology is meaningfully integrated with appropriate learning models rather than applied independently.

Based on these results, educators are encouraged to incorporate interactive and immersive digital technologies alongside constructivist learning models in mathematics instruction, especially in geometry learning. Such integration can create richer learning environments that promote spatial visualization, conceptual understanding, and higher order thinking skills. For future research, it is recommended that experimental or quasi experimental designs be employed to further investigate the effectiveness of specific combinations of technologies and learning models in authentic classroom settings, as well as to explore their long-term impact on students' spatial development.

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