International Electronic Journal of Mathematics Education
2026, 21(2), em0876
e-ISSN: 1306-3030
https://www.iejme.com

MODESTUM

Review Article

OPEN ACCESS

A systematic review of research on geometric thinking: Publication trends and methodological profiles (2018–2024)

Selin Demiray [1*], Merve Koştur [1]

[1] Başkent Universıty, TÜRKİYE
***Corresponding Author:** selindemiray@baskent.edu.tr

Citation: Demiray, S., & Koştur, M. (2026). A systematic review of research on geometric thinking: Publication trends and methodological profiles (2018–2024). *International Electronic Journal of Mathematics Education, 21*(2), em0876. https://doi.org/10.29333/iejme/18180

ARTICLE INFO

Received: 25 Mar 2025

Accepted: 10 Jan 2026

ABSTRACT

This study systematically reviews research on geometric thinking published between 2018 and 2024 to identify key trends and research orientations in the field. A total of 123 peer-reviewed journal articles retrieved from the Web of Science and ERIC databases were analyzed using content analysis. The review examined temporal publication trends, geographic distribution, keywords, research methods, data analysis techniques, sample groups, and data collection instruments. Findings show a marked increase in publications in 2021, followed by a decline, indicating non-linear growth in research. Studies were predominantly conducted in Europe and Asia, with Türkiye and Indonesia as leading contributors. Keyword analysis highlights geometry, geometric thinking, spatial ability, and the van Hiele framework as central themes. Qualitative approaches and content-based analyses were most common, while mixed-methods designs were limited. Middle school students constituted the primary sample group, and tests, tasks, and interviews were the most frequently used instruments. The findings suggest a strong focus on identifying students' geometric thinking levels and underscore the need for methodological diversification and broader participant inclusion.

Keywords: geometric thinking, geometry education, Web of Science, ERIC, systematic literature review

INTRODUCTION

Geometry, one of the key branches of mathematics, is a systematic network that focuses on understanding, analyzing, and explaining relationships within physical and imaginary environments through reasoning and representations of various concepts (Battista, 2007). In this context, geometry enables individuals to enhance their mathematical thinking processes and provides a rich learning environment for developing foundational geometric thinking skills. By its very nature, geometry manifests itself in every aspect of life. From early childhood, it is learned intuitively through the recognition of shapes in the environment and the evaluation of their positions. As individuals enter the school years, their geometric intuition and knowledge become critical for the development of geometric thinking and problem-solving abilities (Clements et al., 2001; Gutiérrez, 1992; Han, 2007; van Hiele, 1999). For this reason, it is widely argued that geometry should be integrated into every stage of basic education (National Council of Teachers of Mathematics, 2000). Within this process, geometric thinking stands out as a key skill that enables the understanding and application of geometry.

Geometric thinking is regarded as a multidimensional cognitive construct that describes individuals' processes of making sense of and using geometric concepts. It encompasses abilities such as perceiving shapes intuitively, identifying their characteristic features, establishing relationships between shapes based on these features, reasoning about shape properties, and uncovering patterns across different axiomatic systems (Clements et al., 2001; Deniz & Kabael, 2021; Lewellen, 1992). In particular, geometric thinking plays a vital role in helping students concretize abstract concepts and connect them to real-life situations, thereby enhancing these skills. For this reason, structuring geometric thinking processes enables students to learn in a multifaceted way and build connections across various disciplines. Geometric thinking focuses on geometric content, including shapes and their properties, transformations, position, and visualization. These differences may stem from individuals' varying levels of geometric knowledge, learning experiences, and diversity in their thinking processes. While geometry equips individuals with spatial thinking skills, it also grounds abstract concepts in concrete foundations (Battista et al., 2018). Throughout this process, individuals' geometric understanding evolves through distinct stages that are critical to educators' teaching and learning.

One of the most frequently used theoretical frameworks in studies on geometric thinking is the van Hiele Geometric Thinking Model, shown in **Figure 1**. Developed by Pierre Marie van Hiele and Dina van Hiele-Geldof, this model proposes that students progress through five levels in learning geometry: Visualization, Analysis, Informal Deduction, Deduction, and Rigor (van Hiele, 1957, as cited in Fuys et al., 1984). At the Visualization level, students recognize shapes as whole entities; at the Analysis level, they

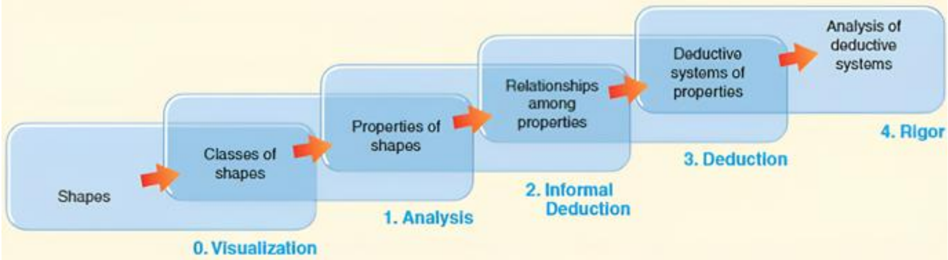

Figure 1. The van Hiele theory of geometric thought (Van de Walle et al., 2013)

identify the properties of shapes; at the Informal Deduction level, they perceive relationships between shapes; at the Deduction level, they make logical inferences within axiomatic systems; and at the Rigor - Systematic Thinking - level, they can compare the axiomatic systems of different geometries. The model is widely accepted worldwide for understanding the developmental dimensions of geometric thinking (Duatepe Paksu, 2016).

In recent years, research has expanded the van Hiele model in both scope and application. It has been shown that the model is not limited to two-dimensional shapes but can also be applied to contexts like three-dimensional geometric thinking, transformation geometry, and dynamic geometry software (Gutiérrez, 1992; Johnson-Gentile et al., 1994). Additionally, it has been highlighted that transitions between levels do not always follow a strict order, and individuals may exhibit characteristics of multiple levels at once or show flexibility between levels depending on the task (Gutiérrez et al., 1991). Some research has also connected the van Hiele model with other cognitive frameworks, such as the SOLO taxonomy (Biggs & Collis, 1982), to offer a more detailed explanation of the multidimensional nature of geometric thinking (Olive, 1991; Pegg & Davey, 1999).

Although the van Hiele model remains a key reference in geometric thinking research, the literature indicates that geometric thinking is more of a multidimensional ability shaped by the interaction among various cognitive processes. Therefore, geometric thinking is considered a dynamic construct involving spatial visualization, spatial reasoning, the use of representations, and metacognition. One fundamental component of geometric thinking is spatial visualization, the ability to mentally represent, manipulate, and reconstruct the positions, orientations, and relationships of two- or three-dimensional objects (Battista, 2007; Presmeg, 2006). This skill plays a critical role in tasks such as transformation geometry, perspective drawing, folding and unfolding operations, and 3D modeling. Research has shown that students with strong spatial visualization skills perform better in geometry problem-solving and produce more creative solutions in mathematical modeling processes (Gutiérrez, 1996; Hegarty & Waller, 2005; Turgut & Yılmaz, 2012). Thus, spatial visualization supports mental operations on shapes and their relationships, which constitute a key dimension of geometric thinking.

Another dimension of geometric thinking is spatial reasoning, which involves making logical inferences about spatial relationships, forms, and movements (Clements & Sarama, 2014). Spatial reasoning encompasses understanding position, orientation, distance, symmetry, and topological relationships, and making logical connections between these concepts. Through this skill, students can analyze relationships between geometric objects based on formal definitions, generalize patterns, and transfer knowledge across contexts (Mix & Cheng, 2012). Therefore, together with spatial visualization, spatial reasoning integrates both perceptual and logical aspects of geometric thinking, playing a central role in problem-solving and conceptual understanding (Resnick et al., 2020; Young et al., 2018). Additionally, the use of representations, such as diagrams, models, and digital visualizations, supports these skills by enabling students to express spatial information, deepen conceptual understanding, and develop alternative solution strategies (Goldin & Kaput, 1996).

The effective development of these cognitive processes depends on students' ability to monitor, evaluate, and regulate their own thinking as they practice with relevant tasks. Metacognition refers to an individual's awareness of their cognitive processes and the ability to control them consciously (Flavell, 1979). Mathematical metacognition encompasses strategies for planning, monitoring, and evaluating problem-solving and reasoning processes (Schoenfeld, 1987). Research indicates that students with higher metacognitive awareness are more successful at selecting strategies and detecting errors in geometry problems (Desoete & De Craene, 2019). Metacognitive skills allow students to decide how to use information, systematically monitor their solution processes, and adjust strategies as needed. Metacognition is particularly critical in analyzing complex spatial relationships and multi-step geometric reasoning processes (Harris, 2023).

Geometric thinking is also shaped by the cultural and contextual conditions in which students are immersed (Bishop, 1991; Gerdes, 1999). Curriculum design, pedagogical approaches, instructional materials, access to technology, and societal values are key factors influencing this process (Presmeg, 2006). For instance, in some cultures, geometry instruction is conducted through real-life contexts and concrete materials, whereas in others, abstract and axiomatic approaches predominate (Iskandar et al., 2022). Similarly, variations in curriculum content, learning objectives, and assessment practices across countries can lead to differences in students' spatial reasoning strategies (Pinilla, 2024; Sinclair & Bruce, 2015). In this sense, cultural diversity influences students' problem-solving approaches, classification strategies, conceptual generalizations, and how geometric knowledge is acquired.

In conclusion, geometric thinking is a multidimensional and dynamic skill situated at the intersection of theoretical models, cognitive processes, metacognitive awareness, and cultural context. Systematically examining recent studies conducted between 2018 and 2024 helps update the theoretical framework and provides insights for practical applications. This study aimed at identifying gaps in literature by offering a holistic perspective that can guide future research and inform how geometry instruction is shaped across different contexts.

LITERATURE REVIEW

Recent literature on geometric thinking has focused particularly on areas such as the van Hiele geometric thinking model, technology integration, spatial reasoning, and student achievement. While these studies have provided important insights into the teaching and development of geometric thinking, they have been limited in offering a comprehensive framework regarding methodological diversity and sample distributions.

Literature reviews focusing on the van Hiele model and technology integration have emerged as prominent topics in the field. Hassan et al. (2020) examined studies conducted between 1998 and 2019. They reported that the stages of the van Hiele model have strong effects when supported by digital tools (e.g., Geometer's Sketchpad, Google SketchUp), while manipulative applications had more limited effects. Similarly, Trimurtini et al. (2022) reviewed 36 studies from 2017 to 2021 and found that van Hiele-based applications supported by technology or concrete materials achieved high effect sizes, yet reaching the highest levels of geometric thinking remained challenging. Abidin et al. (2018) analyzed 17 studies published between 2009 and 2017 and demonstrated that the use of GeoGebra and Sketchpad improved students' achievement, understanding, reasoning, and attitudes, particularly helping lower spatial ability students bridge learning gaps. Sert Çelik and Kaleli Yılmaz's (2022) meta-synthesis covering 83 studies from 2003 to 2020 reported that dynamic geometry software increased students' geometric thinking levels, although these levels generally remained below expectations. Across these reviews, it is evident that most studies focused on topic-centered analyses, while methodological aspects were addressed to a relatively limited extent.

The literature also includes reviews that specifically address the conceptual diversity of geometric thinking. Fachrudin and Juniati (2023), examining studies from 2003 to 2023, identified ten different types of thinking, including creative mathematical reasoning, geometric reasoning, van Hiele-based geometric thinking, and visual-spatial reasoning. Jablonski and Ludwig (2023) analyzed approximately 50 articles and conference papers from 2017 to 2022, highlighting themes such as teacher education, argumentation, proof, digital tools, spatial reasoning, and the role of language in constructing geometric meaning. These studies contribute conceptual richness to different dimensions of geometric thinking but provide limited information regarding data collection tools and methodological diversity.

Trends in geometric thinking research have also been revealed through bibliometric studies. Naufal et al. (2024), reviewing 33 studies from 2011 to 2021, reported an increase in publications over the last decade, with qualitative and quasi-experimental designs predominating, and most participants being middle school students. Kedikli and Katrancı (2021) analyzed 71 graduate dissertations from 2005 to 2019 and highlighted variables such as achievement, attitude, and spatial ability, with polygons and geometric solids as the most frequently studied topics. Aydemir (2021) conducted a bibliometric review of 109 articles indexed in SSCI and ESCI, noting a steady increase in publications, with quantitative methods more common in SSCI and qualitative methods more prevalent in ESCI.

When examining systematic reviews in the field of geometric thinking, it is evident that most studies focus on specific sub-themes or specific topics. Some research has targeted particular areas, such as technology use, geometric thinking levels, or spatial reasoning, while others have addressed geometric thinking more broadly. However, many of these studies have not provided a comprehensive evaluation of the field as a whole, nor have they presented diverse research topics, methodological trends, and data collection approaches in comparative terms. This limitation hinders the holistic assessment of existing findings and impedes clear guidance for future research.

Geometric thinking plays a fundamental role in the development of students' skills in mathematical reasoning, problem-solving, visualization, and the establishment of conceptual connections (Battista, 2007). Therefore, studying geometric thinking offers a comprehensive perspective not only on students' geometry achievement but also on their overall mathematical understanding and cognitive development. Systematically revealing research trends in the field contributes not only to deepening theoretical knowledge but also to the development of effective instructional strategies.

This study aims to address the gaps in previous systematic reviews by examining the field of geometric thinking comprehensively, comparing methodological trends, and critically integrating findings from the literature. The studies were analyzed within a defined framework, and the findings were presented systematically. This approach seeks to clarify the different dimensions of geometric thinking and provide a foundation for future research. Accordingly, the findings from the reviewed studies were analyzed according to the following research questions:

RQ1 What is the distribution of the reviewed studies by publication year?

RQ2 What is the geographical distribution of the reviewed studies?

RQ3 What are the most frequently used keywords in the studies?

RQ4 What research methods were employed in the studies?

RQ5 What types of participants or samples were included in the studies?

RQ6 What data collection instruments were used in the studies?

RQ7 What data analysis methods were applied in the studies?

METHODS

In this study, a systematic literature review was conducted based on established criteria. A systematic literature review involves identifying, evaluating, and interpreting accessible research to address targeted research questions (Kitchenham, 2004).

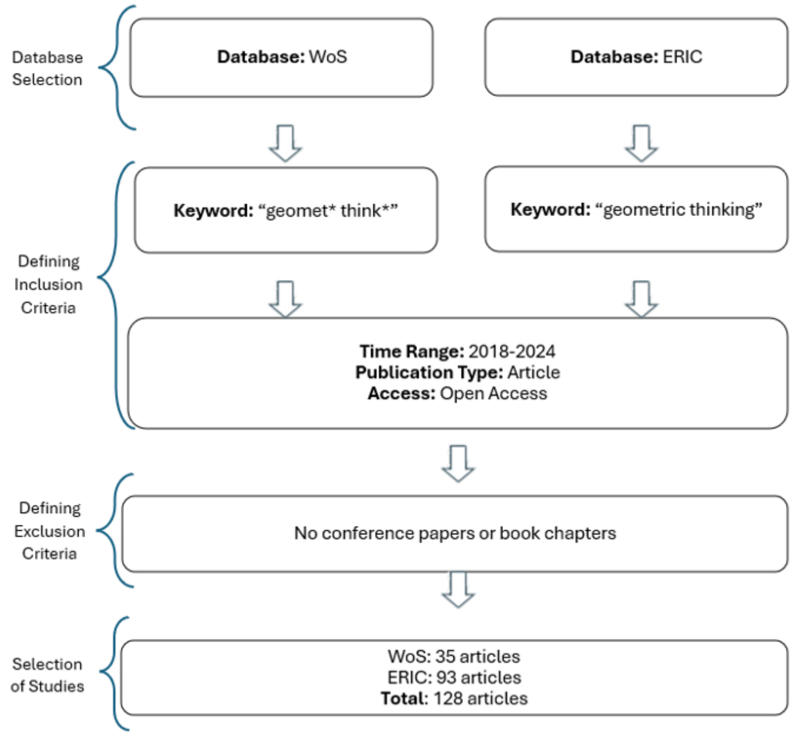

Figure 2. Article selection process and criteria for research (Adapted from Kitchenham, 2004)

Systematic reviews can be utilized to collect primary data within studies (Clarke, 2011). Accordingly, 123 articles related to geometric thinking were examined. To explain the obtained information and answer the research questions, content analysis was employed as the method. Content analysis involves a systematic approach that encompasses all studies on a given topic, assessing their trends and findings in an explanatory manner (Krippendorff, 2019).

Screening Process and Reviewed Studies

The selection of studies to be reviewed followed guidelines proposed by Kitchenham (2004), adapted for this literature review. To identify the studies, the Web of Science (WoS) and Educational Resource Information Center (ERIC) databases were used. These databases were chosen due to their comprehensive content and scientific functionality, which support a wide range of knowledge domains (Li et al., 2018). As keywords, “geomet* think*” was selected for the WoS database to capture all publications related to geometric thinking, while “geometric thinking” was chosen for the ERIC database. The search was conducted within the full texts of the articles. The following inclusion and exclusion criteria for the identified studies were applied as shown in **Figure 2**.

1. Being indexed in either the WoS or ERIC databases,
2. The inclusion of the keywords “geomet* think*” for the WoS database and “geometric thinking” for the ERIC database,
3. Falling within the date range of 2018 to 2024,
4. Being openly accessible,
5. Being published as an article.

After applying the exclusion criteria, 128 articles were identified during the detailed review process. Of these, five articles appeared in both databases and were therefore examined only within the ERIC database. As a result, a total of 123 articles meeting the specified criteria were analyzed.

Data Analysis

The 123 identified articles were examined based on the established inclusion and exclusion criteria. Each article selected for review was analyzed in depth. In this context, the year of publication, geographic distribution, the most frequently used keywords, research methods, participants’ demographic characteristics, data collection tools, and data analysis methods were evaluated for each article. The findings were presented in tables, expressed as percentages and frequencies.

FINDINGS

The results on each research question are presented in this section under subheadings. The findings obtained and the interpretations of these findings are provided beneath each respective heading. Although 123 articles were reviewed, totals in some tables exceed this number because several studies employed multiple methods, participant groups, data collection tools, or data analysis techniques. Therefore, higher totals in some tables reflect the multiplicity of methodological characteristics within individual studies and should not be interpreted as indicating a greater number of studies.

Table 1. Distribution of reviewed articles by year

	2018	2019	2020	2021	2022	2023	2024	Total
Web of Science	-	3	1	7	4	6	9	30
ERIC	11	10	13	22	19	10	8	93
Total	11	13	14	29	23	16	17	123

Table 2. Geographical distribution of the reviewed articles

Continent	Country	N	%
Europe	Türkiye	31	26.1
	Slovakia	5	4.2
	Spain	3	2.5
	Italy	3	2.5
	Greece	2	1.7
	United Kingdom	1	0.8
	Czech Republic	1	0.8
	Portugal	1	0.8
	Hungary	1	0.8
	Sweden	1	0.8
	Total	49	41.2
Asia	Indonesia	19	16.0
	Malaysia	5	4.2
	Israel	4	3.4
	South Korea	2	1.7
	China	2	1.7
	Saudi Arabia	1	0.8
	Kazakhstan	1	0.8
	Sri Lanka	1	0.8
	Philippines	1	0.8
	Palestine	1	0.8
	Japan	1	0.8
	Total	38	31.9
Africa	South Africa	7	5.9
	Ghana	4	3.4
	Namibia	1	0.8
	Egypt	1	0.8
	Tunisia	1	0.8
	Total	14	11.8
North America	USA	9	7.6
	Total	9	7.6
South America	Colombia	4	3.4
	Brazil	3	2.5
	Ecuador	1	0.8
	Total	8	6.7
Australia	Australia	1	0.8
	Total	1	0.8
Total		119	100

Distribution of Publications on Geometric Thinking by Year

Data regarding the publication years of the reviewed studies are presented in **Table 1**. A total of 123 articles were published between 2018 and 2024. The number of publications fluctuates over the years.

As shown in **Table 1**, the number of publications, which was 11 in 2018, increased to 13 and 14 in 2019 and 2020, respectively, and reached its highest level of 29 in 2021. After this point, a declining trend is evident; the number dropped to 23 in 2022 and further to 16 in 2023. Although the number rose slightly to 17 in 2024, the increase remained limited. The publications were particularly concentrated in 2021, whereas the following years showed a relative decrease.

Distribution of Publications on Geometric Thinking by Geographic Regions

It should be noted that although a total of 123 studies were included in the systematic review, five of these studies were theoretical in nature and did not involve an empirical research context and were therefore excluded from the geographical classification. In addition, one of the included studies reported findings from two distinct geographical contexts. As a result, a total of 119 studies are represented in **Table 2**.

The findings reveal that research output is predominantly concentrated in Europe (41.2%) and Asia (31.9%). In Europe, Türkiye's high level of representation (n = 31, 26.1%) indicates that a substantial portion of research in this field is conducted in Türkiye. In addition, more limited contributions are observed from countries such as Spain (n = 3, 2.5%), Slovakia (n = 5, 4.2%), and Greece (n = 2, 1.7%).

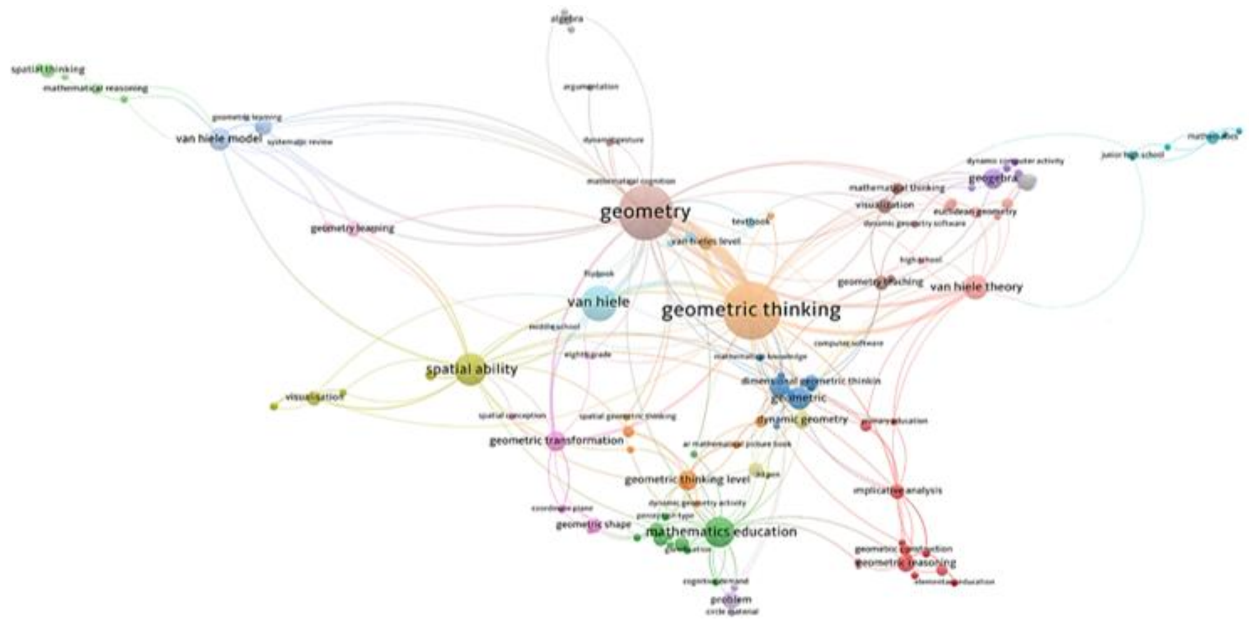

Figure 3. Network visualization of keyword co-occurrence in the publications (Source: Authors' own elaboration, using VOSviewer software)

Table 3. Distribution of research methods

	2018	2019	2020	2021	2022	2023	2024	Total	%
Qualitative	4	6	6	18	11	8	8	61	49.6
Quantitative	4	6	5	7	6	7	5	40	32.5
Mixed	3	1	1	3	5	1	3	17	13.8
Theoretical	-	-	2	1	1	-	1	5	4.1
Total	11	13	14	29	23	16	17	123	100

In Asia, Indonesia (n = 19, 16%) shows a notable concentration, followed by Malaysia, Israel, and China. Although representation from Africa is relatively limited, South Africa (n = 7, 5.9%) stands out. In North America, only the United States is represented (n = 9, 7.6%), while in South America, a small number of contributions are identified from Brazil (n = 3, 2.5%), Colombia (n = 4, 3.4%), and Ecuador (n = 1, 0.8%), The table demonstrates a multi-continental diversity in the geographical distribution of research contexts, although the studies are concentrated in specific countries.

Most Frequently Used Keywords in Publications Related to Geometric Thinking

A total of 525 keywords were identified in the reviewed studies. Among these, 55 keywords that appeared at least two times were analyzed using the VOSviewer program to examine their co-occurrence relationships, and the resulting network visualization is presented in **Figure 3**.

The analysis indicates that geometric thinking (n = 32), geometry (n = 30), and mathematics education (n = 20) are among the most frequently used keywords in literature. These are followed by spatial ability (n = 18) and a set of keywords representing the van Hiele framework, namely van Hiele (n = 16), van Hiele theory (n = 11), and van Hiele model (n = 9). In addition, keywords such as geometric reasoning (n = 6), geometric transformation (n = 6), and GeoGebra (n = 6) also appear with notable frequency.

The network visualization in **Figure 3** illustrates the most frequently used keywords in the reviewed publications and the structural relationships among them. In this map, the thickness of the connecting lines represents the strength of the co-occurrence between keywords, indicating how often they appear together within the same studies. The size of each node reflects the frequency of use of the corresponding keyword, while the colors represent distinct thematic clusters formed based on co-occurrence patterns.

As shown in **Figure 3**, geometry and geometric thinking occupy central positions in the network and exhibit the highest frequencies, highlighting their dominant role in literature. These core concepts are strongly connected to spatial ability, mathematics education, and van Hiele, suggesting a close conceptual relationship between geometric thinking, cognitive skills, and instructional frameworks. The clustering of van Hiele theory, van Hiele model, and geometric thinking level further underscores the sustained influence of the van Hiele framework in the conceptualization and analysis of geometric thinking. Moreover, the presence of geometric transformation and its connections with both geometric thinking and spatial ability point to a research emphasis on the dynamic and transformational aspects of geometry learning. Overall, the network reveals a coherent thematic structure in which research on geometric thinking is predominantly situated within educational and cognitive contexts.

Research Methods Used in Publications on Geometric Thinking

The distribution of the research methods used in the reviewed articles by year is presented in **Table 3**.

Table 4. Distribution of the data analysis methods

	2018	2019	2020	2021	2022	2023	2024	Total	%
Content analysis	5	6	6	18	15	7	9	66	35.9
Descriptive analysis	6	5	8	10	10	9	11	59	32.1
Statistical analysis	6	4	7	7	12	5	7	48	26.1
Document analysis	-	2	-	-	4	3	2	11	6
Total	17	17	21	35	41	24	29	184	100

Table 5. Distribution of data analysis methods by research method

	Content analysis	Descriptive analysis	Statistical analysis	Document analysis
Qualitative	46	28	2	8
Quantitative	9	16	30	1
Mixed	9	14	15	1
Theoretical	2	1	1	1
Total	66	59	48	11

Table 6. Distribution of sample used in the reviewed studies

Samples	2018	2019	2020	2021	2022	2023	2024	Total	%
Middle school students	3	4	5	6	7	7	5	37	28.7
High school students	2	3	3	7	1	2	6	24	18.6
Primary school students	4	1	4	7	2	1	4	23	17.8
Pre-service teachers	1	1	-	7	4	1	2	16	12.4
Documents - publications	-	2	1	2	5	2	1	13	10.1
Teachers	-	2	1	2	3	-	-	8	6.2
Preschool students	-	-	-	1	1	2	-	4	3.1
Undergraduate students	-	-	1	-	1	1	-	3	2.3
Parents	-	1	-	-	-	-	-	1	0.8
Total	10	14	15	30	24	16	18	129	100

According to **Table 3**, qualitative methods are predominant in the studies (49.6%; n = 61), while quantitative studies (32.5%; n = 40) and mixed-method studies (13.8%; n = 17) constitute a limited proportion. In addition, a small number of theoretical studies are also present (4.1%; n = 5). When the distribution across years is analyzed, a notable increase is observed in all research methods in 2021, reaching a total of 29 studies. In the remaining years, the number of publications fluctuates.

Data Analysis Methods Used in Studies on Geometric Thinking

The distribution of data analysis methods employed in the reviewed studies by year and overall percentages is presented in **Table 4**.

Table 4 shows that the most frequently used data analysis methods were content analysis (35.9%; n = 66) and descriptive analysis (32.1%; n = 59), followed by statistical analysis (26%; n = 48). A small number of studies also employed document analysis (6%; n = 11). When examined by year, content analysis reached its highest frequency in 2021 (n = 18), while descriptive analysis peaked in 2024 (n = 11). Additionally, some of the reviewed studies applied more than one data analysis method simultaneously. The distribution of this diversity according to research methods is presented in **Table 5**.

According to **Table 5**, the most frequently used methods in qualitative research were content analysis (n = 46) and descriptive analysis (n = 28). In addition, document analysis (n = 8) and statistical analysis (n = 2) were used less frequently. In quantitative studies, statistical analysis (n = 30) was the predominant method, followed by descriptive analysis (n = 16) and content analysis (n = 9). In mixed-methods studies, statistical analysis (n = 15), descriptive analysis (n = 14), and content analysis (n = 9) were used together; document analysis (n = 1) also appeared in a small number of studies. In theoretical studies, content analysis, statistical analysis, descriptive analysis, and document analysis were each employed to a limited extent (n = 1-2).

Samples in the Publications on Geometric Thinking

The distribution of the samples preferred in the reviewed studies by year and percentage is presented in **Table 6**.

When **Table 6** is examined, the most frequently preferred sample group across the studies is middle school students (28.7%, n = 37). This group is followed by high school students (18.6%, n = 24) and primary school students (17.8%, n = 23). In addition, pre-service teachers (12.4%, n = 16) and documents – publication analyses (10.1%, n = 13) also constitute a considerable proportion of the samples. Less frequently preferred samples include teachers (6.2%, n = 8), preschool students (3.1%, n = 4), undergraduate students (2.3%, n = 3), and parents (0.8%, n = 1).

Data Collection Tools Used in Publications on Geometric Thinking

The distribution of data collection tools used in the reviewed studies by year and percentage is presented in **Table 7**.

Upon examining **Table 7**, tests emerge as the most frequently used data collection tool (28.4%, n = 55), followed by tasks (16.5%, n = 32) and interviews (14.9%, n = 29). Observations (9.8%, n = 19) and activities (8.8%, n = 17) are also among the commonly employed instruments. Open-ended questions (7.2%, n = 14), video records (5.7%, n = 11), questionnaires (5.7%, n = 11), and scales

Table 7. Distribution of data collection tools used in the reviewed studies

	2018	2019	2020	2021	2022	2023	2024	Total	%
Test	5	5	5	12	12	8	8	55	28.4
Task	4	2	7	6	6	3	4	32	16.5
Interview	1	4	3	8	7	3	3	29	14.9
Activity	1	3	2	5	2	1	3	17	8.8
Observation	2	3	-	6	2	2	4	19	9.8
Video records	3	1	2	2	1	1	1	11	5.7
Open-ended questions	-	3	1	6	4	-	-	14	7.2
Questionnaire	2	2	-	5	1	1	-	11	5.7
Scale	-	1	-	2	-	1	2	6	3.1
Total	18	24	20	52	35	20	25	194	100

Table 8. Data collection tools used according to participant groups

	Test	Task	Interview	Activitiy	Observation	Video records	Open-ended questions	Questionnaire	Scale
Middle school students	19	7	8	3	2	5	3	1	1
High school students	9	6	5	4	5	2	3	3	1
Primary school students	12	8	5	5	5	1	1	2	2
Pre-service teachers	10	7	4	1	-	-	3	2	3
Teachers	1	3	3	1	2	3	2	2	-
Preschool students	3	-	3	-	1	1	-	-	1
Undergraduate students	3	1	2	1	1	-	-	1	-
Parents	-	-	1	-	-	-	-	1	-

(3.1%, n = 6) were used less frequently. In some studies, multiple data collection tools were employed. The distribution of this methodological diversity across participant groups is presented in **Table 8**.

An examination of **Table 8** indicates that tests and tasks are the most commonly used data collection tools across participant groups. In studies involving middle school, high school, and primary school students, tests and tasks are particularly prominent, while interviews, activities, and observations are used as complementary tools. Research conducted with pre-service teachers includes not only tests and tasks but also questionnaires and scales. In studies involving in-service teachers, interviews and tasks are frequently employed, along with video recordings and open-ended questions. For preschool and undergraduate students, tests and interviews emerge as the dominant tools, whereas in the single study involving parents, interviews and questionnaires were preferred.

CONCLUSION AND DISCUSSION

The temporal distribution of the reviewed publications reveals a notable increase in 2021, suggesting that geometric thinking gained heightened visibility within the research agenda during this period. This trend is consistent with previous bibliometric findings indicating growing scholarly interest in geometric thinking (Aydemir, 2021). However, the subsequent decline observed in 2022 and 2023 indicates that this growth was not sustained, pointing to the non-linear nature of publication trends. Such fluctuations may be associated with period-specific factors, including curriculum reforms, shifts in funding priorities, and broader changes in educational research agendas following the COVID-19 pandemic. From a theoretical perspective, the surge in 2021 may reflect renewed attention to foundational frameworks such as the van Hiele model and spatial reasoning, which continue to shape instructional and applied research in geometry education (Battista et al., 2018; Hoffer, 1983). While the overall pattern supports earlier reports of increasing research output (Kedikli & Katrancı, 2021; Naufal et al., 2024), it also highlights the lack of long-term stability in publication growth.

The geographic distribution of research contexts indicates an intense concentration in Europe (41.2%) and Asia (31.9%), with Türkiye and Indonesia emerging as the most prominent contributors. This concentration aligns with earlier studies reporting substantial growth in geometric thinking research within these countries (Kedikli & Katrancı, 2021; Naufal et al., 2024). Research conducted in Türkiye and Indonesia primarily focuses on identifying students' geometric thinking levels, examining achievement-related variables, and conducting practice-oriented descriptive studies. In contrast, studies originating from Europe and other regions more frequently engage with broader theoretical and pedagogical perspectives, including technology integration and classroom-based spatial reasoning frameworks (Hassan et al., 2020; Jablonski & Ludwig, 2023). These differences suggest that geographic context plays a critical role in shaping research orientations, methodological choices, and pedagogical emphases. Although literature reflects a degree of multi-continental diversity, the uneven geographic representation underscores the need for future research to incorporate a broader range of cultural and educational contexts.

Keyword analysis further demonstrates that the field is conceptually anchored in geometry and geometric thinking, which occupy a central position in literature. Frequently associated keywords, such as spatial ability, mathematics education, van Hiele theory, geometric transformation, and geometric thinking level, indicate a strong emphasis on cognitive models and level-based frameworks. This pattern is consistent with the foundational role attributed to the van Hiele theory in explaining students' geometric thinking processes (Clements & Battista, 1992) and with research highlighting the importance of spatial reasoning in geometry learning (Presmeg, 2006). At the same time, the relatively limited visibility of concepts related to metacognition, representation, and socio-cultural context suggests that these dimensions remain underexplored. This imbalance points to a conceptual gap in literature, where cognitive perspectives dominate at the expense of pedagogical and contextual considerations.

Methodologically, the reviewed studies are characterized by a predominance of qualitative approaches, reflecting the need to examine students' conceptual understanding of geometric thinking in depth. This orientation aligns with Battista's (2007) characterization of geometric thinking as a multidimensional cognitive construct. Quantitative studies, while less prevalent, primarily focus on experimental designs that measure instructional effects and van Hiele levels, thereby contributing to the production of generalizable findings (Aydemir, 2021). However, the reliance on traditional experimental and statistical techniques suggests limited engagement with advanced modeling or longitudinal approaches. Despite their strong potential to integrate process-oriented and outcome-based perspectives, mixed-methods designs remain relatively underrepresented (Creswell & Plano Clark, 2018). In parallel, data analysis techniques are confined mainly to content analysis, descriptive analysis, and basic statistical procedures. Although there is a precise alignment between research designs and analytical strategies, the dominance of traditional analytical approaches underscores a need for greater methodological diversification to better capture the dynamic, evolving nature of geometric thinking.

Regarding participants, middle school students are the most frequently studied group, followed by high school and primary school students. This distribution reflects longstanding views that these educational stages are critical for the development of geometric understanding (Crowley, 1987; Jones, 2002). In contrast, studies involving pre-service teachers, in-service teachers, preschool students, undergraduates, and parents remain limited. Given the central role of teachers in shaping classroom practices and mediating students' learning experiences, the underrepresentation of teacher-focused research constitutes a significant gap in the literature (Fujita & Jones, 2007).

Consistent with the participant profile, tests emerge as the most commonly used data collection instrument, particularly standardized tools such as the van Hiele Geometry Level Test (Burger & Shaughnessy, 1986; Usiskin, 1982). The dominance of tests reflects researchers' preference for reliably classifying geometric thinking levels and obtaining comparable results across samples. Nevertheless, the notable use of tasks and interviews indicates a growing interest in capturing process-oriented data, including students' reasoning, problem-solving strategies, and conceptual understanding. Task-based approaches allow researchers to examine how students engage with geometric problems, while interviews provide rich insights into individual thinking processes. This tendency is consistent with Cobb and Bauersfeld's (1995) emphasis on the explanatory value of qualitative data derived from classroom interactions. Although observations, video recordings, and open-ended questions are used less frequently, their complementary roles suggest emerging efforts to enhance methodological richness across multiple data sources. Taken together, these findings indicate that while traditional instruments remain dominant, there is a gradual shift toward more diverse and interactive approaches that can illuminate the complex and dynamic nature of geometric thinking.

RECOMMENDATIONS

The findings point to several directions for strengthening future research on geometric thinking. Although qualitative and quantitative approaches are widely employed, the limited use of mixed-methods designs restricts the integration of process- and outcome-oriented insights. Future studies should more systematically adopt mixed-methods frameworks to capture both learners' reasoning processes and measurable learning outcomes. Moreover, reliance on conventional analytic techniques suggests the need for methodological innovation. Advanced analytic approaches, such as learning analytics, process mining, and multimodal data analysis, may offer richer representations of the dynamic nature of geometric thinking.

The intense concentration on middle and high school populations indicates an imbalance in literature. Expanding research to include preschool learners, undergraduate students, teachers, and parents would support a more developmental and contextualized understanding of geometric thinking across educational stages. Additionally, while the Van Hiele model and digital tools remain central, future research should move beyond established frameworks by examining how emerging technologies, such as AR, VR, and AI-supported environments, reshape learners' geometric reasoning, particularly through scaffolded instructional designs.

LIMITATIONS

Several limitations should be considered when interpreting the findings. The study was confined to WoS and ERIC databases, which may have resulted in the omission of relevant publications indexed elsewhere. The selected time span, 2018 - 2024, while suitable for identifying recent trends, limits conclusions about longitudinal shifts in the field. Finally, the exclusion of conference proceedings and book chapters may have reduced the visibility of emerging practices and theoretical developments.

Author contributions: SD: Conceptualization, data collection, data analysis, writing – original draft; **MK:** Methodology, writing – review & editing. All authors have agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: The authors stated that this study is based solely on document analysis and does not involve human participants or interventions; therefore, ethics committee approval was not required.

AI statement: The authors stated that no generative artificial intelligence or AI-based tools were used for the writing, editing, or data analysis of this article.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Abidin, M., Ismail, Z., & Ismail, N. (2018). Geometrical thinking with technology: A systematic literature review. *2018 IEEE 10th International Conference on Engineering Education (ICEED)* (pp. 230-235). IEEE. https://doi.org/10.1109/ICEED.2018.8626949

Aydemir, G. (2021). *Geometri eğitimi üzerine yayınlanan makalelerin WoS veri tabanına dayalı bibliyometrik analizi* [Bibliometric analysis of articles published on geometry education based on the WoS database] [Unpublished master's thesis]. Amasya University.

Battista, M. T. (2007). The development of geometric and spatial thinking. In F. K. Lester (Ed.), *Second handbook of research on mathematics teaching and learning* (pp. 843-908). Information Age.

Battista, M. T., Frazee, L. M., & Winer, M. L. (2018). Analyzing the relation between spatial and geometric reasoning for elementary and middle school students. In K. Mix, & M. Battista (Eds.), *Visualizing mathematics* (pp. 195-228). Springer. https://doi.org/10.1007/978-3-319-98767-5_10

Biggs, J. B., & Collis, K. F. (1982). *Evaluating the quality of learning: The SOLO taxonomy (Structure of the observed learning outcome).* Academic Press. https://doi.org/10.1016/C2013-0-10375-3

Bishop, A. J. (1991). *Mathematical enculturation: A cultural perspective on mathematics education.* Springer. https://doi.org/10.1007/978-94-009-2657-8

Burger, W. F., & Shaughnessy, J. M. (1986). Characterizing the van Hiele levels of development in geometry. *Journal for Research in Mathematics Education, 17*(1), 31-48. https://doi.org/10.2307/749317

Clarke, J. (2011). What is a systematic review? *Evidence-Based Nursing, 14*(3), Article 64. https://doi.org/10.1136/ebn.2011.0049

Clements, D. H., & Battista, M. T. (1992). Geometry and spatial reasoning. In D. A. Grouws (Ed.), *Handbook of research on mathematics teaching and learning: A project of the National Council of Teachers of Mathematics* (pp. 420-464). National Council of Teachers of Mathematics. https://doi.org/10.1108/978-1-60752-874-620251022

Clements, D. H., & Sarama, J. (2014). *Learning and teaching early math: The learning trajectories approach* (2nd ed.). Routledge. https://doi.org/10.4324/9780203520574

Clements, D. H., Battista, M. T., & Sarama, J. (2001). Logo and geometry. *Journal for Research in Mathematics Education Monograph, 10*. https://doi.org/10.2307/749924

Cobb, P., & Bauersfeld, H. (1995). Introduction: The coordination of psychological and sociological perspectives in mathematics education. In P. Cobb, & H. Bauersfeld (Eds.), *The emergence of mathematical meaning: Interaction in classroom cultures* (pp. 1–16). Routledge.

Creswell, J. W., & Plano Clark, V. L. (2018). *Designing and conducting mixed methods research* (3rd ed.). Sage Publications.

Crowley, M. L. (1987). The van Hiele model of the development of geometric thought. In M. M. Lindquist (Ed.), *Learning and teaching geometry, K-12* (pp. 1-16). National Council of Teachers of Mathematics.

Deniz, Ö., & Kabael, T. (2021). Investigation of sixth-grade students' cognitive processes in a learning trajectory designed for basic geometric constructions. *Education and Science, 46*(206), 47–90. https://doi.org/10.15390/EB.2020.9328

Desoete, A., & De Craene, B. (2019). Metacognition and mathematics education: An overview. *ZDM Mathematics Education, 51*(4), 565-575. https://doi.org/10.1007/s11858-019-01060-w

Duatepe Paksu, A. (2016). Van Hiele geometrik düşünme düzeyleri [Van Hiele geometric thinking levels]. In E. Bingölbali, S. Arslan, & İ. Ö. Zembat (Eds.), *Matematik eğitiminde teoriler* [Theories in mathematics education] (pp. 265-275). Pegem Akademi.

Fachrudin, A. D., & Juniati, D. (2023). Kinds of mathematical thinking addressed in geometry research in schools: A systematic review. *Jurnal Riset Pendidikan Dan Inovasi Pembelajaran Matematika, 6*(2), 154-165. https://doi.org/10.26740/jrpipm.v6n2.p154-165

Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive–developmental inquiry. *American Psychologist, 34*(10), 906-911. https://doi.org/10.1037/0003-066X.34.10.906

Fujita, T., & Jones, K. (2007). Learners' understanding of the definitions and hierarchical classification of quadrilaterals: Towards a theoretical framing. *Research in Mathematics Education, 9*(1), 3-20. https://doi.org/10.1080/14794800008520167

Fuys, D. J., Geddes, D., & Tischler, R. W. (Eds.). (1984). *English translation of selected writings of Dina van Hiele-Geldof and Pierre M. van Hiele.* Brooklyn College, School of Education.

Gerdes, P. (1999). *Geometry from Africa: Mathematical and educational explorations.* Mathematical Association of America.

Goldin, G. A., & Kaput, J. J. (1996). A joint perspective on the idea of representation in learning and doing mathematics. In L. Steffe, P. Nesher, P. Cobb, G. A. Goldin, & B. Greer (Eds.), *Theories of mathematical learning* (pp. 397-430). Lawrence Erlbaum.

Gutiérrez, A. (1992). Exploring the links between van Hiele levels and 3-dimensional geometry. *Structural Topology, 18*, 31-48.

Gutiérrez, A. (1996). Visualization in 3-dimensional geometry: In search of a framework. In L. Puig & A. Gutiérrez (Eds.), *Proceedings of the 20th International Conference for the Psychology of Mathematics Education* (pp. 3-19). Valencia, Spain: International Group for the Psychology of Mathematics Education.

Gutiérrez, A., Jaime, A., & Fortuny, J. M. (1991). An alternative paradigm to evaluate the acquisition of the van Hiele levels. *Journal for Research in Mathematics Education, 22*(3), 237-251. https://doi.org/10.2307/749076

Han, H. (2007). *Middle school students' quadrilateral learning: A comparision study* [Doctoral dissertation]. University College London.

Harris, D. (2023). Spatial reasoning in context: Bridging cognitive and educational perspectives of spatial-mathematics relations. *Frontiers in Education, 8*. https://doi.org/10.3389/feduc.2023.1302099

Hassan, M. N., Abdullah, A. H., & Ismail, N. (2020). Effects of integrative interventions with van Hiele phase on students' geometric thinking: A systematic review. *Journal of Critical Reviews, 7*(13), 270-277. https://doi.org/10.31838/jcr.07.13.194

Hegarty, M., & Waller, D. A. (2005). Individual differences in spatial abilities. In P. Shah, & A. Miyake (Eds.), *The Cambridge handbook of visuospatial thinking* (pp. 121-169). Cambridge University Press. https://doi.org/10.1017/CBO9780511610448.005

Hoffer, A. (1983). Van Hiele-based research. In R. Lesh, & M. Landau (Eds.), *Acquisition of mathematical concepts and processes* (pp. 205-227). Academic Press Inc.

Iskandar, R. S. F., Karjanto, N., Kusumah, Y. S., & Ihsan, I. R. (2022). *A systematic literature review on ethnomathematics in geometry*. arXiv. https://doi.org/10.48550/arXiv.2212.11788

Jablonski, S., & Ludwig, M. (2023). Teaching and learning of geometry—A literature review on current developments in theory and practice. *Education Sciences, 13*(7), Article 682. https://doi.org/10.3390/educsci13070682

Johnson-Gentile, K., Clements, D. H., & Battista, M. T. (1994). Effects of computer and noncomputer environments on students' conceptualizations of geometric motions. *Journal of Educational Computing Research, 11*(2), 121-140. https://doi.org/10.2190/49EE-8PXL-YY8C-A923

Jones, K. (2002). Issues in the teaching and learning of geometry. In L. Haggarty (Ed.), *Aspects of teaching secondary mathematics: Perspectives on practice* (pp. 121-139). Routledge.

Kedikli, D., & Katrancı, Y. (2021). Geometrik düşünme düzeyleri ile ilgili tezlerin betimsel içerik analizi [Descriptive content analysis of theses about geometric thinking levels]. *Kocaeli University Journal of Education, 4*(2), 251-273. https://doi.org/10.33400/kuje.950983

Kitchenham, B. (2004). *Procedures for performing systematic reviews* (Technical Report TR/SE-0401). Keele University.

Krippendorff, K. (2019). *Content analysis: An introduction to its methodology* (4th ed.). SAGE. https://doi.org/10.4135/9781071878781

Lewellen, H. (1992). *Description of van Hiele levels of geometric development with respect to geometric motions* [Unpublished doctoral dissertation]. Kent State University.

Li, K., Rollins, J., & Yan, E. (2018). Web of Science use in published research and review papers 1997–2017: A selective, dynamic, cross-domain, content-based analysis. *Scientometrics, 115*(1), 1-20. https://doi.org/10.1007/s11192-017-2622-5

Mix, K. S., & Cheng, Y.-L. (2012). The relation between space and math: Developmental and educational implications. In J. B. Benson (Ed.), *Advances in child development and behavior* (pp. 197-243). Elsevier. https://doi.org/10.1016/B978-0-12-394388-0.00006-X

National Council of Teachers of Mathematics. (2000). Principles and standards for school mathematics. NCTM.

Naufal, M. A., Abdullah, A. H., Zainal, Z., Ihsan, H., Zaki, A., & Alshaye, I. A. (2024). The trend of geometric thinking studies: A systematic review. *The 6th IndoMS International Conference on Mathematics and Applications, 58*, Article 03010. EDP Sciences. https://doi.org/10.1051/itmconf/20245803010

Olive, J. (1991). Logo programming and geometric understanding: An in-depth study. *Journal for Research in Mathematics Education, 22*(2), 90-111. https://doi.org/10.5951/jresematheduc.22.2.0090

Pegg, J., & Davey, G. (1999). Interpreting student understanding in geometry: A synthesis of two models. In R. Lehrer, & D. Chazan (Eds.), *Designing learning environments for developing understanding of geometry and space* (pp. 109-133). Routledge.

Pinilla, R. K. (2024). Spatial reasoning in mathematics standards: Identifying how early elementary educators are systematically supported to teach spatial skills. *Frontiers in Education, 9.* https://doi.org/10.3389/feduc.2024.1407388

Presmeg, N. C. (2006). Research on visualization in learning and teaching mathematics. In A. Gutiérrez, & P. Boero (Eds.), *Handbook of research on the psychology of mathematics education: Past, present and future* (pp. 205-235). Sense Publishers. https://doi.org/10.1163/9789087901127_009

Resnick, I., Harris, D., Logan, T., & Lowrie, T. (2020). The relation between mathematics achievement and spatial reasoning. *Mathematics Education Research Journal, 32*(2), 171-174. https://doi.org/10.1007/s13394-020-00338-7

Schoenfeld, A. H. (1987). What's all the fuss about metacognition? In A. H. Schoenfeld (Ed.), *Cognitive science and mathematics education* (pp. 189-215). Routledge.

Sert Çelik, H., & Kaleli Yılmaz, G. (2022). Analysis of van Hiele geometric thinking levels studies in Turkey: A meta-synthesis study. *International Journal of Curriculum and Instruction, 14*(1), 473-501.

Sinclair, N., & Bruce, C. D. (2015). New opportunities in geometry education at the primary school. *ZDM Mathematics Education, 47*(3), 319-329. https://doi.org/10.1007/s11858-015-0693-4

Trimurtini, Waluya, S. B., Sukestiyarno, Y. L., & Kharisudin, I. (2022). A systematic review on geometric thinking: A review research between 2017–2021. *European Journal of Educational Research, 11*(3), 1535-1552. https://doi.org/10.12973/eu-jer.11.3.1535

Turgut, M., & Yılmaz, S. (2012). Relationships among preservice primary mathematics teachers' gender, academic success and spatial ability. *International Journal of Instruction, 5*(2), 35-52.

Usiskin, Z. (1982). *Van Hiele levels and achievement in secondary school geometry.* University of Chicago.

Van de Walle, J. A., Karp, K. S., & Bay-Williams, J. M. (2013). *Elementary and middle school mathematics: Teaching developmentally* (8th ed.). Pearson.

van Hiele, P. M. (1999). Developing geometric thinking through activities that begin with play. *Teaching Children Mathematics, 5*(6), 310-316. https://doi.org/10.5951/TCM.5.6.0310

Young, C. J., Levine, S. C., & Mix, K. S. (2018). The connection between spatial and mathematical ability across development. *Frontiers in Psychology, 9*. https://doi.org/10.3389/fpsyg.2018.00755