

Bibliometric Analysis of Spatial Thinking Research in Elementary Education: Global Trends from 2015 to 2025

Syafrizal Isnain Maulana✉, State University of Surabaya, Indonesia

Dini Rahma Wati Handono Putri, State University of Surabaya, Indonesia

Azzahra Qurota A'yun, State University of Surabaya, Indonesia

Zaenal Abidin, State University of Surabaya, Indonesia

Felmar Roy S. Adam, Mindanao State University, Philipina

✉ 24010644038@mhs.unesa.ac.id

Abstract: Spatial thinking supports learning in mathematics and other STEM-related domains, and classroom studies have examined how it can be developed in elementary education. Limited research has examined how this body of work is distributed over time, which records attract the most citations, and which themes co-occur in the literature. This study aims to map publication trends, citation patterns, and term co-occurrence structures of research on spatial thinking in elementary education published between 2015 and 2025. The study extends previous synthesis work by applying bibliometric mapping to the elementary education level. Records were retrieved from Google Scholar through Publish or Perish using the search term “spatial thinking in elementary school” and analyzed with VOSviewer. The search returned 420 records. Annual output rose from 27 records in 2015 to a peak of 67 in 2020 and declined to 3 records in 2025, a year that may be incompletely covered. Title-based classification of the ten most cited records showed that one addressed spatial thinking among elementary students, one addressed spatial ability among middle school students, and the remaining records addressed other forms of thinking or STEM education more broadly. Term co-occurrence analysis identified 103 terms in six clusters, with student, spatial thinking, and elementary school as the most frequent terms. The findings suggest that, within this retrieved set, highly cited records combining a spatial focus with an elementary-level focus are limited. Because the data source is Google Scholar, the results should be interpreted with caution and tested through replication in curated databases.

Keywords: Spatial Thinking; Elementary Education; Bibliometric Analysis; VOSviewer.

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INTRODUCTION

Spatial thinking encompasses cognitive processes involved in representing, transforming, and reasoning about the locations, shapes, and relationships of objects and spaces. Related constructs include spatial ability, spatial skills, and discipline-specific spatial thinking (Wai et al., 2009; Uttal, Meadow, et al., 2013; Lee & Bednarz, 2012). Atit et al. (2020) emphasized the role of disciplinary context in spatial thinking, while Buckley et al. (2018) proposed a framework for translating spatial ability research into STEM education.

Spatial ability has been associated with educational and occupational outcomes in STEM domains (Wai et al., 2009). Reviews have examined its relationship with mathematical competencies (Hawes & Ansari, 2020), while early childhood evidence links spatial skills with later spatial performance and mathematics skills (Verdine et al., 2017). Spatial skills are also malleable through training. Uttal et al. (2013) synthesized 217 training studies and reported an average effect size of $g = 0.47$, including transfer to untrained spatial tasks. Hawes et al. (2022) reviewed 29 controlled studies and found improvements in mathematics performance, particularly among older participants and in interventions using concrete materials. Elementary classroom interventions have likewise reported improvements in spatial and numerical skills, spatial ability, and mathematics performance (Hawes et al., 2017; Lowrie et al., 2017; Lowrie et al., 2019).

Spatial thinking research in elementary education involves curriculum, pedagogy, teachers' pedagogical content knowledge, and classroom practices (Bufasi et al., 2024). Previous studies have examined spatial training, spatial ability measurement, and applications in STEM learning (Hawes et al., 2022; Zhu et al., 2023). Research remains limited regarding how studies in elementary education are distributed over time, which records receive the most citations, and which themes co-occur in broadly retrieved academic records. Bibliometric analysis can address these questions by mapping publication patterns, citation visibility, and thematic structures (Donthu et al., 2021).

Bibliometric analysis provides a structured approach to examining publication patterns and thematic development (Donthu et al., 2021), while VOSviewer supports the visualization of bibliometric networks, including term co-occurrence (van Eck & Waltman, 2010). Google Scholar was selected for its broad coverage across disciplines. Martín-Martín et al. (2021) found that it retrieved the largest share of citations among the sources they compared. However, limitations in precision, recall, and reproducibility

affect its suitability for systematic searching (Gusenbauer & Haddaway, 2020). These limitations inform the interpretation of the present findings.

The purpose of this study is to map research on spatial thinking in elementary education published between 2015 and 2025 through bibliometric analysis. Specifically, the study addresses three research questions: (1) How did the annual number of retrieved records change between 2015 and 2025? (2) Which records received the most citations, and how many of these addressed spatial thinking among elementary school students? (3) Which thematic clusters emerged from the co-occurrence of terms in the retrieved records?

METHODS

Research Design

This study used a descriptive bibliometric design, which quantifies bibliographic attributes of a defined set of publications and visualizes their relationships (Donthu et al., 2021). The procedure consisted of three stages: data collection, data identification, and data visualization.

Data Source and Search Strategy

Bibliographic records were retrieved from Google Scholar through the Publish or Perish software. The search term was “spatial thinking in elementary school,” the publication window was 2015 to 2025, and article titles served as the guiding criterion for the search. The search returned 420 records. These records were analyzed as retrieved by the search engine and formed the dataset for the annual publication analysis and the citation analysis.

Data Identification

Annual publication counts were obtained from the publication year of each record, and percentages were calculated relative to the total of 420 records. Records were ranked by citation count, and the ten most cited records were examined. The title of each record was read to classify (a) whether it addressed spatial thinking or a related spatial construct and (b) whether it addressed elementary school students.

Data Visualization and Analysis

VOSviewer was used to construct term co-occurrence maps from the retrieved abstracts and keywords. Network, overlay, and density visualizations were generated. Terms were characterized by occurrence counts and total link strength, then grouped using the

VOSviewer clustering procedure (van Eck & Waltman, 2010). Cluster labels were interpreted descriptively based on their constituent terms.

RESULTS

Annual Publication Trend (RQ1)

Table 1 presents the annual number of retrieved records. The dataset contained 420 records in total. Output increased from 27 records in 2015 to 37 in 2016 and 2017, and to 58 in 2018. It then decreased to 48 in 2019 and reached the highest annual count of 67 in 2020 (15.95% of the dataset). After 2020, the counts were 53 in 2021, 44 in 2022, 24 in 2023, 22 in 2024, and 3 in 2025. The period from 2018 to 2022 contributed 270 records (64.29%).

Table 1. Annual number of records retrieved for “spatial thinking in elementary school”

Year	Number of records	Percentage (%)
2015	27	6.43
2016	37	8.81
2017	37	8.81
2018	58	13.81
2019	48	11.43
2020	67	15.95
2021	53	12.62
2022	44	10.48
2023	24	5.71
2024	22	5.24
2025	3	0.71
Total	420	100.00

Year-to-year decreases after the 2020 peak were 14 records (2020 to 2021), 9 records (2021 to 2022), 20 records (2022 to 2023), 2 records (2023 to 2024), and 19 records (2024 to 2025). The largest decrease occurred between 2022 and 2023, followed by the decrease between 2024 and 2025.

Citation Patterns (RQ2)

Table 2 lists the ten most cited records in the dataset.

Table 2. The ten most cited records retrieved for “spatial thinking in elementary school”

Cites	Authors	Year	Cites/Yr
509	N. M. Fuad, S. Zubaidah, S. Mahanal, E. Suarsini	2017	63.63
401	J. Leonard, A. Buss, R. Gamboa, M. Mitchell, et al.	2016	44.56
400	S. Zubaidah, N. M. Fuad, S. Mahanal, et al.	2017	50.00
394	Y. Li, A. H. Schoenfeld, A. A. Disessa, A. C. Graesser, et al.	2019	65.67
326	T. Lowrie, T. Logan, A. Ramful	2017	40.75
305	I. Lee, S. Grover, F. Martin, S. Pillai, et al.	2020	61.00

279	A. Ramful, T. Lowrie, T. Logan	2017	34.88
250	R. Lamb, T. Akmal, K. Petrie	2015	25.00
244	S. York, R. Lavi, Y. J. Dori, M. K. Orgill	2019	40.67
222	D. J. Ketelhut, K. Mills, E. Hestness, L. Cabrera, et al.	2020	44.40

Note. Metadata are reproduced as retrieved from Publish or Perish (Google Scholar).

The most cited record, with 509 citations (63.63 citations per year), was an article by Fuad and colleagues. Its title refers to critical thinking among junior high school students and contains no reference to spatial constructs. The second most cited record, by Leonard and colleagues (401 citations), concerns robotics and game design in relation to children's self-efficacy, STEM attitudes, and computational thinking.

Classification based on titles produced four groups. One record, by Lowrie et al. (2017), addressed spatial thinking among elementary students through visuospatial training and mathematics performance. One record, by Ramful et al. (2017), addressed the measurement of spatial ability among middle school students. One record, by Ketelhut and colleagues, addressed teacher change in integrating computational thinking into elementary science, which concerns the elementary level without a spatial focus. The remaining seven records referred to critical, creative, computational, design, or systems thinking, or to STEM education more broadly, without reference to spatial constructs.

Keyword Co-occurrence Mapping (RQ3)

VOSviewer produced network, overlay, and density visualizations. The network visualization showed 103 terms divided into six clusters. Each term has a number of occurrences and a total link strength. Across the network, the total link strength was 5,976 and the total number of links was 2,436. Table 3 lists the terms in each cluster.

Table 3. Clusters identified through term co-occurrence analysis

Cluster	Color	Items	Terms
1	Red	26	activity, addition, analysis, area, case study, child, concept, education, educator, effect, elementary school teacher, game, geography, geospatial technology, GIS, knowledge, mathematical thinking, place, role, school, sense, spatial thinking, spatial thinking skill, teacher, teaching, tool
2	Green	20	achievement, aspect, gender, improvement, mental rotation, middle school student, motivation, performance, primary school, relation, relationship, spatial ability, spatial orientation, spatial reasoning, spatial skill, spatial visualization, study, term, type, year
3	Dark blue	19	approach, creative thinking, creative thinking skill, creativity, geometry, grade, implementation, Indonesia, inquiry, problem, process, project, representation, shape, skill, space, STEM, student, thinking

4	Yellow	18	augmented reality, computational thinking, critical thinking skill, effectiveness, elementary school, elementary school student, impact, influence, lack, learning, mathematics, medium, program, research, science, science learning, technology, young child
5	Purple	16	ability, assessment, challenge, context, development, elementary school child, elementary student, goal, instrument, model, paper, present study, reasoning, time, understanding, use
6	Light blue	4	application, article, geometric thinking, level

Descriptively, Cluster 1 contains terms related to geography, geospatial technology, and teachers. Cluster 2 contains spatial ability constructs together with terms such as gender, achievement, and motivation. Cluster 3 contains terms related to creativity, inquiry, geometry, and STEM. Cluster 4 contains terms related to computational thinking, critical thinking, augmented reality, and science learning. Cluster 5 contains terms related to assessment, instruments, and reasoning. Cluster 6 contains four terms, including geometric thinking.

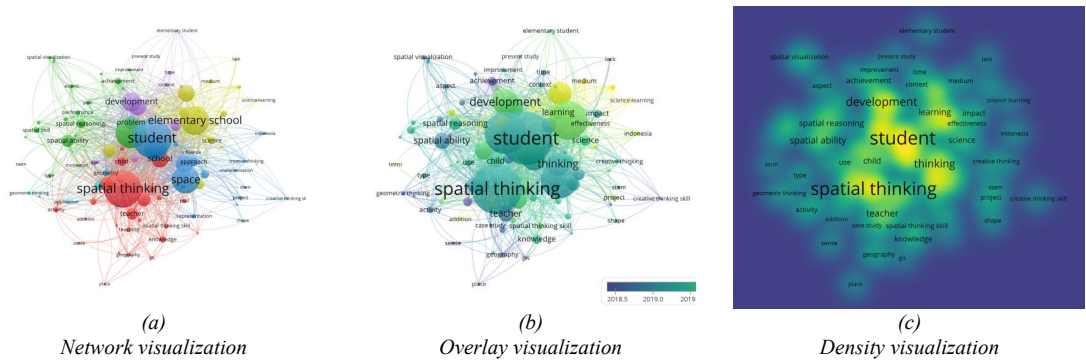


Figure 1. Bibliometric Visualization of Spatial Thinking Research in Elementary Education

Three terms showed the highest occurrence and total link strength. The term student appeared 125 times with a total link strength of 649, spatial thinking appeared 118 times with a total link strength of 560, and elementary school appeared 91 times with a total link strength of 456.

DISCUSSION

Publication Trend and Its Interpretation

The retrieved records increased from 27 in 2015 to a peak of 67 in 2020, followed by lower annual counts. The low count for 2025 may reflect incomplete coverage at the time of retrieval, while indexing delays may affect the representation of recent publications (Martín-Martín et al., 2021). The single search phrase may also have excluded relevant studies using terms such as spatial ability, spatial skills, or spatial reasoning.

Consequently, the observed decline describes the retrieved dataset and cannot independently establish a decline in the field. Replication using broader search terms, a documented retrieval date, and a curated database could assess the stability of this pattern.

Citation Visibility of Spatial Thinking Research in Elementary Education

Among the ten most cited records, one addressed spatial thinking among elementary students, one examined spatial ability among middle school students, and one concerned computational thinking in elementary science. The other seven addressed different forms of thinking or STEM education more broadly. This distribution may reflect the broad search phrase, which can retrieve records whose titles do not explicitly identify spatial constructs. Citation counts may also reflect differences in topic audience and publication visibility.

Terminology varies across related research. Lowrie et al. (2017) examined visuospatial training and mathematics performance, while Ramful et al. (2017) developed and validated the Spatial Reasoning Instrument for middle school students. Other studies examined spatial and numerical skills in early geometry instruction (Hawes et al., 2017), spatial reasoning following teacher-delivered training (Lowrie et al., 2019), and spatial thinking in geography education (Lee & Bednarz, 2012; Bednarz & Lee, 2019). These differences in terminology suggest that a search using one phrase may not capture the full range of relevant studies.

Within the ten most cited records, few combined an explicit spatial focus with an elementary-level focus. This finding concerns citation visibility within the retrieved subset and does not establish the prevalence of such research across the field. Future analyses should combine related terms, including spatial thinking, spatial ability, spatial reasoning, spatial skills, and visuospatial skills, and apply documented relevance screening.

Thematic Structure of the Retrieved Literature

The co-occurrence analysis identified six clusters, with student, spatial thinking, and elementary school showing the highest occurrence counts and link strengths. Because these terms overlap with the search phrase, their prominence should be interpreted alongside the other terms in each cluster.

Cluster 2 includes mental rotation, spatial orientation, and spatial visualization, which correspond to constructs in the Spatial Reasoning Instrument (Ramful et al., 2017)

and skills targeted in classroom interventions (Lowrie et al., 2017). Cluster 1 includes geography, GIS, and geospatial technology, consistent with research using spatial thinking assessments in geography education (Lee & Bednarz, 2012). Bednarz and Lee (2019) reviewed 22 studies using such an assessment and identified instructional strategies and learner characteristics associated with spatial thinking. Cluster 5 reflects assessment and instrumentation, including early childhood spatial skills measurement (Verdine et al., 2017).

Clusters 3 and 4 include creative, critical, and computational thinking, STEM, and augmented reality, consistent with the prominence of broader thinking-related topics among the highly cited records. Gender appears in Cluster 2 alongside achievement, motivation, and performance. Lauer et al. (2019) synthesized 128 studies involving participants aged 3–18 years to examine the development of gender differences in spatial reasoning. However, term co-occurrence does not indicate the direction or magnitude of such differences. Indonesia also appears in Cluster 3 alongside inquiry, project work, creativity, STEM, and geometry. The available data do not establish why this country term occurs in the cluster.

The clusters suggest themes involving spatial ability, geography and GIS education, creativity-oriented STEM learning, technology-supported thinking, and assessment. These interpretations can guide construct selection and further investigation of connections among spatial thinking, geometry, computational thinking, and technology in elementary education. Instruments developed for older students, such as the Spatial Reasoning Instrument, require validation before use with younger learners (Ramful et al., 2017).

Implications for Research and Practice

Although this bibliometric study did not assess instructional effectiveness, previous empirical findings offer relevant implications for practice. Spatial activities can be integrated into elementary mathematics instruction (Hawes et al., 2017; Lowrie et al., 2017). Hawes et al. (2022) reported stronger effects for interventions using concrete materials and for older participants, while noting that transfer mechanisms remain poorly understood. Curriculum alignment, pedagogy, and teachers' pedagogical content knowledge are also relevant to spatial teaching (Bufasi et al., 2024). Authentic STEM learning provides another context for developing spatial ability (Zhu et al., 2023).



Limitations and Directions for Future Research

Several limitations should be considered. First, the study relied exclusively on Google Scholar, whose precision, recall, and reproducibility limitations may affect the relevance of retrieved records (Gusenbauer & Haddaway, 2020). Second, the search used one phrase and did not apply documented relevance screening to all 420 records. Third, classification of the ten most cited records relied on titles, which may not fully represent their content. Fourth, citation counts are affected by publication age, and 2025 coverage may be incomplete. Fifth, cluster interpretations were descriptive. Finally, the analysis did not examine authorship, institutional affiliations, journals, or country collaboration.

Future research should use multiple search terms, documented screening procedures, and additional databases such as Scopus or Web of Science. Further bibliometric analyses could examine authorship and international collaboration, while a systematic review of elementary-level interventions could investigate instructional effectiveness.

CONCLUSION

This study mapped publication trends, citation patterns, and term co-occurrence in research on spatial thinking in elementary education from 2015 to 2025. The Google Scholar search retrieved 420 records, with annual output peaking at 67 records in 2020. Among the ten most cited records, one focused on spatial thinking among elementary students, one on spatial ability among middle school students, and one on computational thinking in elementary science. Term co-occurrence analysis identified 103 terms across six clusters, indicating several thematic strands within the retrieved literature. These findings are subject to the limitations of a single-source, single-phrase search and the incomplete coverage of 2025. Future studies should use broader search terms, documented relevance screening, and additional databases to develop a more comprehensive account of spatial thinking research in elementary education.

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