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Review Article

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Investigating current patterns in spatial learning within the context of mathematics education in Asia: A systematic review

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ABSTRACT

Many studies conducted across the world have demonstrated the significant benefits of adding spatial thinking abilities to learning activities. Spatial embedded activities have a significant effect in enhancing the students' achievements in many ways, including in the STEM subject. However, the application of spatial talents in the curriculum remains limited. This systematic literature study will examine Asia's spatial ability-based learning trend for the past ten years (from 2014 to early 2024) and its benefits on students' academic progress. This study was conducted in February 2024 and gathered studies from three different journal databases, including Education Resources Information Center, Scopus, and Web of Science. The PICO (participants, interventions, comparisons, and outcomes) framework was used in this study to collect articles using specific keywords. The criteria were satisfied by 23 articles, which were incorporated into this study. The findings indicate that research conducted in Asia pertaining to spatial learning incorporated three distinct types of spatial strategies: spatial embedded assignments, spatial learning technologies, and spatial embedded teaching strategies. Utilizing these three strategies to implement spatial learning activities was beneficial for teachers and students. However, further research is required to elucidate the factors that impact the implementation of spatial learning, such as the cultural context of Asian countries.

Keywords: spatial learning, spatial thinking, mathematics education, systematic literature review, PICO

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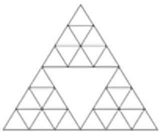
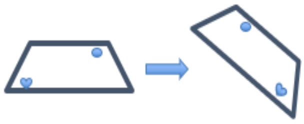
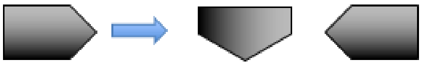
INTRODUCTION

Spatial learning is one of the instructional methods that emphasizes the use of spatial thinking and skills (Plummer et al., 2022). Teachers bear the duty for the development of the students. The more teachers are cognizant of students' development, the more they can choose the most suitable level at which to instruct them (Santrock, 2017; Slavin, 2018). As learning designers, teachers must ensure that students successfully attain the objectives of their studies. In order to attain the learning objectives, educators should employ a diverse range of instructional innovations. This will enable students to not only promptly accomplish the learning goals but also enhance their abilities along the learning journey. Teachers may implement spatial learning as an instructional innovation to improve students' mathematics proficiency. In the learning process, spatial learning employs spatial reasoning, which is the cognitive capacity to employ visual-spatial information to solve mathematical problems, and forming, retaining, and manipulating this information are among the processes that are involved (Yurt & Sünbül, 2014). The correlation between students' success in mathematics and spatial thinking has been demonstrated through academic research, which has demonstrated the beneficial effects of incorporating spatial thinking into mathematics education. Designing spatial-based learning to engage early childhood students in geometrical activities showed students' enhancement in geometry (Novita et al., 2018). Students with good spatial abilities tend to have better academic achievement in mathematics compared to students with low spatial abilities (Camci et al., 2024; Öztürk & Yilmaz, 2023). Another study showed that promoting spatial reasoning and developing early understanding of multiplication on students using embodied mathematics tasks could be one of effective teaching methods (Putrawangsa & Patahuddin, 2022).

Lowrie et al. (2021) found that spatial thinking encompasses the interpretation and manipulation of spatial information to solve problems and make decisions. It is reasonable to regard spatial thinking as an essential element of the learning process, given the pronounced correlation between mathematical abilities and spatial thinking. Inadequate performance in geometry can be attributed to the student's limited proficiency in spatial abilities (Putri, 2018). Furthermore, research has demonstrated that spatial thinking is advantageous for both students and educators. Teachers who possess exceptional spatial thinking are more likely to employ effective language when presenting mathematics materials than those who possess limited spatial thinking. A study conducted by Abidin (2018) that examines the communication

Table 1. Typology of spatial thinking

	Intrinsic (relation within objects)	**Extrinsic (relation among objects or objects in the manipulated situation)**
Static (objects remain in stay in original position)	(*Intrinsic-static*)  Task: How many triangles can you find in that picture?	(*Extrinsic-static*)  Task: Where the heart-shaped icon will be if the first picture is moved
Dynamic (objects moved from original position)	(*Intrinsic-dynamic*)  Task: Which of the images on the right is the same object if the image on the left is rotated by 900 turns clockwise?	(*Extrinsic-dynamic*)  Task: Kate's and William's seating position is shown in the picture. In which position is the flower vase in Kate's view? Sample item from SRI (Ramful et al., 2017, 2023).

on mathematics pre-service teachers shows that spatial thinking has a positive correlation on the way pre-service teachers explain learning material about the area of trapezoid. Also, spatial thinking also has positive influences on teachers in creating innovative mathematics learning activities for students. Another study conducted Jatisunda et al. (2021) also shows that mathematics pre-service teachers who have good spatial skills tend to be more creative in preparing mathematics learning activities than those who have low spatial skills. In order to foster teachers' spatial reasoning and teaching style, implementing heuristics visual-predict-check (VPC) showed a significant effect on teachers (Patahuddin et al., 2020). The implementation of spatial learning can be supported by using learning technologies as supporting media (Hartatiana et al., 2017; Ng & Chan, 2019; Pradana et al., 2020; Tsai & Yen, 2014; Tsai et al., 2015). Experts gave positive feedback for the development of spatial learning using technology to elevate visual-spatial skills and geometry thinking (Wahab et al., 2017; Yahya et al., 2021).

Nevertheless, the significance of spatial thinking has not been adequately addressed in the standard school curriculum. Despite the fact that school curricula frequently emphasize verbal reasoning and mathematics in order to foster children's success, they frequently disregard spatial thinking and reasoning as critical abilities (Newcombe, 2018; Wai & Uttal, 2018). The objective of this investigation is to investigate the extent to which spatial ability-based learning is prevalent in Asia and the beneficial effects it has on the academic performance of students. Spatial learning is implemented primarily in Western countries, as indicated by the previous studies (Lakin et al., 2024; Uttal et al., 2013). A systematic review of the implementation of spatial learning in mathematics education, with a particular emphasis on Asian countries, can be highly beneficial for a variety of reasons. Understanding regional educational trends, challenges, and opportunities and their correlation with the broader global landscape of mathematics education is one of the most compelling reasons to conduct such a review. Cultural, economic, and historical factors frequently influence the unique methods that Asian countries employ in the teaching of mathematics. For example, Singapore, Japan, and China are recognized for their exceptional performance in international assessments such as the PISA test (OECD, 2023). These countries employ unique pedagogical approaches that may not be widely recognized outside of the region. A study showed that implementing origami (paper folding), widely known as one of the Japanese cultures, to promote spatial learning gave positive results for elementary students' spatial skills and perceptions (Cakmak et al., 2014). Additionally, the educational context of each Asian country is distinct, which influences the teaching and learning of mathematics. Mathematical education can be influenced by cultural values, teaching traditions, and local educational policies, as revealed by this systematic review.

Researchers with an interest in spatial thinking-related research will acquire valuable insights from this systematic literature review. The aim of this study is to elucidate the trends in the implementation of spatial thinking in Asia over the past decade, with a particular emphasis on the strategies and benefits that have been implemented to facilitate spatial learning. Additionally, this investigation consolidates evidence regarding regional practices, obstacles, and innovations that may advance our comprehension of mathematics instruction and learning. This review has the potential to provide critical insights for the enhancement of education in Asia and throughout the world, given the region's emphasis on mathematics, the diversity of educational systems, and the global implications of effective practices. By conducting a systematic review, this study tried to answer the following research questions (RQs):

1. What is the research trend in Asia related to spatial learning in mathematics education?
2. What strategies have been used for spatial learning implementation in Asia in the last 10 years, from 2014 to early 2024?
3. What are the benefits of implementing spatial learning in mathematics education?

Spatial Learning

Spatial ability is tested, which is the mental capacity to create mental images and manipulate objects mentally. Spatial thinking, on the other hand, is concerned with the location of objects, their shapes, the relationships between them, and the trajectories they follow when they are moved (Newcombe, 2016). In order to advance in spatial thinking, students must exhibit their capacity to employ spatial skills. Static and dynamic skills, which are based on the movement of objects, as well as intrinsic and extrinsic skills, which are based on spatial information, will be employed to construct a typology (Davis, 2015; Ramey et al., 2020). **Table 1** shows the typology of spatial thinking.

In STEM education contexts, teachers can develop students' spatial thinking by introducing them to spatial-embedded media, including graphs, diagrams, and maps (Newcombe, 2016). Teaching students to think spatially can also be achieved by encouraging them to sketch and illustrate. Teachers could acquire a deeper understanding of the ways in which the movements of students' hands and eyes can influence the perception, creation, and interpretation of geometric shapes and patterns by allowing students to draw (Sinclair et al., 2018). Spatial-embedded technologies can also be employed by educators to facilitate the acquisition of spatial skills by students. Research indicates that the utilization of spatial-embedded technologies in educational activities, including mobile devices (Chang et al., 2016; Montag et al., 2021), SketchUp Make (Abdullah et al., 2022; Wahab et al., 2017), and geographic information systems (Newcombe, 2013, 2016), not only improves and facilitates students' spatial thinking but also deepens their comprehension and engagement.

METHODOLOGY

The current study is a systematic review using some literature related to spatial learning intervention studies conducted in Asia. The obtained literature will be analyzed in depth through four steps: formulate the RQs, determine the search terms and appropriate databases, use inclusion and exclusion criteria to ensure the quality of relevant literature, and answer the RQ by extracting, analyzing, and interpreting the obtained literature (Bognar et al., 2024). This study examined publications from three databases: Education Resources Information Center (ERIC), Scopus, and Web of Science (WoS). Those three databases are highly regarded as reliable and valuable databases for academic research, particularly when it comes to the search for peer-reviewed journal articles, conference papers, and other scholarly works. Scopus is recognized for its ability to index peer-reviewed journals of exceptional quality, guaranteeing that the content is reputable and dependable for academic purposes. WoS, like Scopus, provides a comprehensive array of academic content that encompasses a wide range of disciplines. ERIC is the primary resource for individuals who are engaged in educational research. It indexes a diverse array of education-related literature, such as journal articles, reports, research papers, and other materials that are specific to the field of education. All three databases offer sophisticated search capabilities, citation monitoring, and filtering options, which facilitate the navigation process for this study in quest of high-quality sources.

The publications were collected in early 2024 and sorted using keywords related to spatial learning in mathematics education. The PICO (participants, interventions, comparisons, and outcomes) framework was used to ensure comprehensive coverage of the literature and develop an initial search strategy based on the keywords of the publications (Methley et al., 2014). This study determined that participants might include both students and professionals, regardless of their level of expertise, who were engaged in spatial learning activities. Boolean operators were used for keywords to meet the logical condition during the search process. The initial search, which utilized the keywords "spatial" OR "spatial learning" OR "spatial reasoning," "mathematics," and "students," yielded numerous articles that were not directly pertinent to the RQs. The results of the pilot research suggested that the keywords we used for "spatial" were too broad, as they brought up studies that were more closely related to engineering than to education. The concept of "spatial" was refined to "spatial thinking," which focused on the spatial studies that are associated with educational studies. The titles and abstracts of the retrieved articles were reviewed, and a specific term, such as "teaching," was added based on the pilot results. **Table 2** shows the PICO framework in this study.

Table 2. The PICO framework in this study

PICO framework	Categories	Keywords
Intervention	Spatial learning	"Spatial Thinking", "Spatial Learning", "Spatial Skills", "Spatial Reasoning", "Mathematics", "Learning", "Students"
Comparison	Mathematics education	

Following the refinement of our search terms, we conducted a new search in ERIC, Scopus, and WoS using keywords ("spatial reasoning" OR "spatial thinking" OR "spatial learning" OR "spatial skills") AND "mathematics" AND "teaching" AND "students". A total of 198 articles were collected from the three databases using determined keywords. The researchers used inclusion and exclusion criteria to sort the collected articles to ensure the quality of the relevant literature.

The inclusion criteria consist of the language, location of the research, related topic of the study, and targeted participants. In the interim, the exclusion criteria consist of duplicate articles, full-text accessibility, and publication year. The procedure for gathering articles from three targeted journal databases is illustrated in **Figure 1**. Initially, 199 articles were gathered, as illustrated in **Figure 1**. Subsequently, the inclusion and exclusion criteria that were previously delineated were implemented during the filtering process. As anticipated, the majority of the selected studies (88.4%) were from Western countries, while the remaining studies were from Asian countries, which were the topic of the study. The final number of articles obtained was 23, which encompassed studies on spatial learning in mathematics education in Asian countries.

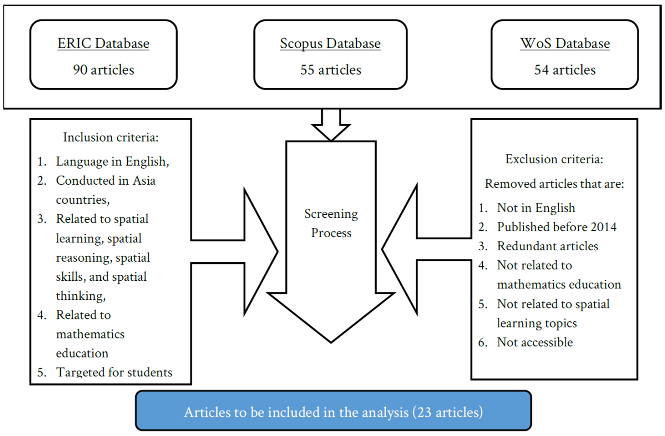


Figure 1. Collecting data procedures (the authors' own work)

RESULTS

To address the RQs, the analysis will comprise 23 articles that were acquired. These articles will serve as a compilation of spatial studies in mathematics education across Asian countries over the past decade.

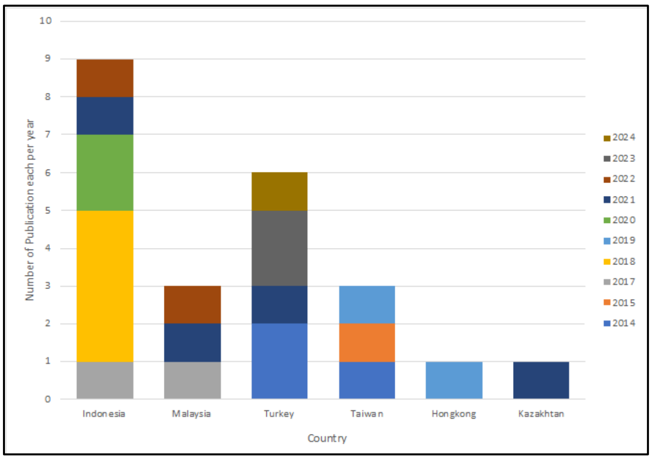


Figure 2. Asian countries that have been engaging in spatial learning from 2014 to early 2024 (the authors' own work)

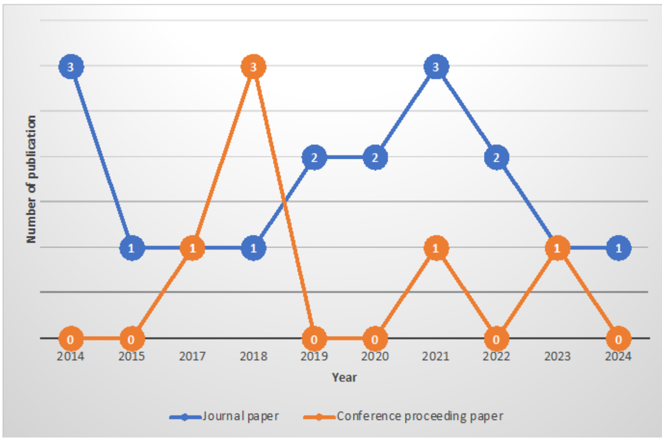


Figure 3. Publication trends in Asia related to spatial learning from 2014 to early 2024 (the authors' own work)

RQ1. What Is the Research Trend in Asia Related to Spatial Learning in Mathematics Education?

Figure 2 shows Asian countries that conducted spatial learning-related studies from 2014 to early 2024.

Indonesia has the most significant number of studies compared to other countries, with 9 publications, followed by Turkey in the second place and Malaysia in the third place. Meanwhile, three countries in Asia, India, Hongkong, and Kazakhstan, had the least number of studies related to spatial learning for the past ten years. The studies were mostly published in 2018 with four articles from Indonesia and in 2021 from four countries (Indonesia, Malaysia, Turkey, and Kazakhstan), with each country publishing one article. These studies were published either as journal papers or conference proceedings, with the representation shown in **Figure 3**.

Figure 3 shows that 75% of the studies related to spatial learning in Asia were published as journal papers, while others were published as conference proceedings. It can also be seen that there has been no significant increase in the number of studies in Asia related to spatial learning throughout the last ten years. Meanwhile, the research topic trend in Asia over the past decade has involved spatial strategies implemented for teaching and learning activities, as detailed in **Figure 4**.

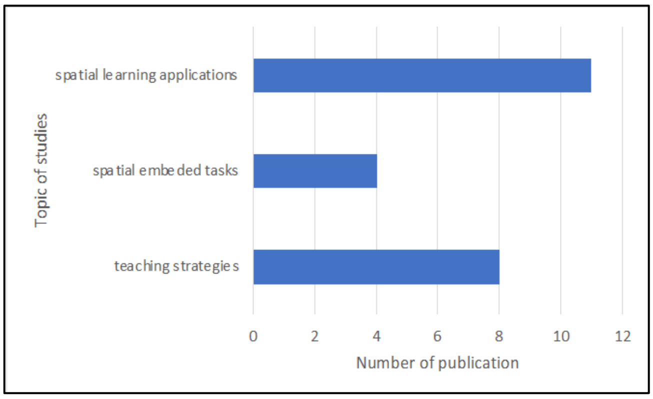


Figure 4. The topic of study trends in Asia related to spatial learning from 2014 to early 2024 (the authors' own work)

As shown in **Figure 4**, spatial embedded technology was specifically implemented in more than 50% of the studies, followed by 35% of the studies interested in the intervention of spatial teaching strategies.

RQ2. What Strategies Have Been Used for Spatial Learning Implementation in Asia From 2014 to Early 2024?

Studies showed the malleability of spatial ability and the positive effect on the participants in terms of enhancing cognitive skills, including problem-solving and reasoning (Ramful et al., 2023; Uttal et al., 2013). **Table 3** shows all the obtained studies, the targeted participants, and the strategies and interventions implemented. The implementation of spatial learning using culture-related activities has shown a positive impact on students' spatial ability, as indicated in the implementation of origami-based instruction (Cakmak et al., 2014).

As previously stated, the majority of spatial embedded technology implementations for spatial studies occurred in Asia. Although numerous tools and technologies are employed, the two most widely utilized were Sketch-Up Make and Microsoft Kinect Sensor. The effective use of Sketch-Up Make as a technological tool in geometry education has been demonstrated, particularly in illustrating to students the virtual manipulation of 3D geometric figures (Abdullah et al., 2022; Wahab et al., 2017; Yahya et al., 2021).

Meanwhile, the game-based technology using Microsoft Kinect Sensor, which was implemented in the education of university students, demonstrated an advantageous effect on the students' comprehension of natural science courses (Tsai & Yen, 2014; Tsai et al., 2015). The integration of technology into spatial learning activities will provide both teachers and students with benefits, particularly in the context of distance education. During the implementation of distance learning, students in a rural region of Turkey were effectively instructed in geometry through the use of a virtual manipulative tool (Eroğlu, 2023). Furthermore, through the use of spatial manipulative technologies, students will have the capacity to independently manipulate the geometrical shape, thereby enhancing their problem-solving capabilities (Hwang et al., 2019; Novita et al., 2018; Öztürk & Yilmaz, 2023). The integration of innovative and integrative teaching strategies, in addition to the utilization of enhanced spatial-related technologies, should be taken into consideration. The application of suitable spatial learning activities can facilitate the development of spatial sense, which is a valuable asset in problem-solving endeavors (Casey & Fell, 2018). The utilization of VPC heuristics and hypothetical learning trajectory (HLT) have been predominantly observed in compiled studies conducted in Asia over the past decade.

The integration of VPC heuristics with GeoGebra, a spatial embedded technology, yields a significant improvement in students' spatial ability, as evidenced by an increase in their spatial scores after the implementation compared to their pre-implementation scores (Öztürk & Yilmaz, 2023). By encouraging the development of students' natural method of thinking, the HLT strategy could aid in the improvement of students' comprehension of particular subjects (Clements & Sarama, 2020). Students' understanding of rectangular prism nets may be significantly enhanced through the implementation of HLT strategies (Camci et al., 2024). The integration of HLT would not only improve students' performance in geometry but also foster development in their spatial reasoning abilities (Novita et al., 2018). Studies have observed that students' spatial reasoning and the ability to design effective lessons improve when teachers utilize both VPC and HLT (Khairunnisak et al., 2018; Patahuddin et al., 2022). Better spatial reasoning on the part of teachers results in more effective learning instruction for students. A positive correlation exists between teachers' proficiency in spatial reasoning and their ability to utilize a diverse range of teaching resources. Specifically, educators who possess strong spatial reasoning tend to employ a greater variety of teaching resources in order to design efficacious learning activities that aid students in their geometry studies, as opposed to educators who have limited spatial reasoning (Jatisunda et al., 2021; Khairunnisak et al., 2018).

Table 3. Studies conducted in Asia related to spatial learning for the past 10 years

Code	Title/author	Purposes of study	Participants	Strategies/ intervention
(1)	Investigating effect of origami-based instruction on elementary students' spatial skills and perceptions (Cakmak et al., 2014)	To investigate the effect of origami-based instruction on elementary students' spatial ability.	Grade 4-6 students from a private school in Turkey.	Origami-based instruction
(2)	A structural equation model explaining 8th grade students' mathematics achievements (Yurt & Sünbül, 2014)	Examine the relationship between variables (mathematical problem-solving, reasoning skills, self-efficacy, spatial ability and mathematics achievement) using a structural equation model.	The 8th grade students from secondary schools in Turkey.	Embedded tests
(3)	Teaching spatial visualization skills using OpenNI and the Microsoft Kinect sensor (Tsai & Yen, 2014)	To investigate the usability and learnability of a cubic-net-assisted learning system using Microsoft Kinect Sensor.	University students at the University of Technology in Taiwan.	OpenNI & Microsoft Kinect Sensor
(4)	Development and evaluation of game-based learning system using the Microsoft Kinect Sensor (Tsai et al., 2015)	To investigate the capability of Microsoft Kinect Sensor in improving teaching and learning as an interactive technology and to develop game-based-learning system using Microsoft Kinect Sensor for learning spatial skills.	University students from a university in northern Taiwan.	Microsoft Kinect Sensor-assisted learning system
(5)	Evaluation by experts and designated users on the learning strategy using SketchUp make for elevating visual spatial skills and geometry thinking (Wahab et al., 2017)	Reporting the result developed learning strategy using SketchUp for elevating students' visual spatial skills and geometry thinking in two final stage of ADDIE instructional design model.	Experts in spatial skills and geometry thinking and students in Malaysia.	SkecthUp to create learning strategy
(6)	Student's spatial reasoning through model eliciting activities with Cabri 3D (Hartatiana et al., 2017)	To find the influence of learning activities using Cabri 3D on the improvement of junior high school students' spatial reasoning	The 7th grade students from a junior high school in Indonesia.	Model eliciting activities learning with Cabri 3D
(7)	Mathematical communication characteristics of pre-service primary school teacher in explaining the area of trapezoid reviewed from school origin (Abidin, 2018)	Examine the characteristics of mathematical communication of pre-service primary school teachers.	University students from primary teacher education program in Indonesia.	Spatial embedded tasks & microteaching
(8)	Design learning in mathematics education: Engaging early childhood students in geometrical activities to enhance geometry and spatial reasoning (Novita et al., 2018)	To design an instructional activity to guide early childhood students in understanding geometry and spatial reasoning.	Kindergarten students age 4-5 years old in Indonesia.	Learning trajectory for geometry learning
(9)	Spatial skill profile of mathematics pre-service teachers (Putri, 2018)	To examine the spatial skill of mathematics pre-service teachers in solving mathematics problems	Mathematics pre-service teachers for secondary school students in Indonesia.	Spatial embedded tasks about geometry
(10)	Teachers' use of learning resources in spatial learning (Khairunnisak et al., 2018)	To develop HLT for teachers using various learning resources to support students' learning geometry.	Mathematics teachers who taught a secondary school in Banda Aceh Indonesia.	Variety of teaching learning resources
(11)	An investigation of the effects of measuring authentic contexts on geometry learning achievement (Hwang et al., 2019)	Examine the impact of ubiquitous geometry (UG) on students' spatial ability, geometry learning achievement, and ability.	Fifth-grade students are from elementary schools in Taiwan.	UG system
(12)	Learning as making: Using 3D computer-aided design to enhance the learning of shape and space in STEM-integrated ways (Ng & Chan, 2019)	To examine the students' mathematics learning with integrated STEM learning practice.	Teachers and students from secondary schools and primary schools in Hongkong.	3D computer-aided design
(13)	Virtual mathematics kits (VMK): The value of spatial orientation on it (Pradana et al., 2020)	Examining the use of VMK on students' spatial orientation skills and evaluating VMK as a digital media on promoting students' spatial reasoning.	Primary school students in Indonesia.	VMK

Table 3 (Continued).

Code	Title/author	Purposes of study	Participants	Strategies/ intervention
(14)	What does teaching of spatial visualization skills incur: an exploration through the visualize-predict-check heuristic (Patahuddin et al., 2020)	Exploring a heuristic VPC on teachers' teaching of visualization and fostering teachers' spatial reasoning.	Two experienced mathematics teachers who taught 7 grades of junior high school in Indonesia	VPC heuristic
(15)	CHEMBOND3D e-module effectiveness in enhancing students' knowledge of chemical bonding concept and visual-spatial skills (Kuit & Osman, 2021)	To investigate the effectiveness of Chembond3D e-module that integrates the web-based visualization tool on the students' chemical bonding concept knowledge and visual-spatial skills.	Students from ten secondary schools in Malaysia.	Chembond3D e-module
(16)	A scale development study intended for mathematics teacher candidates: Mathematical visualization perception scale (Ilhan & Tutak, 2021)	To develop a measurement tool that measures mathematics visualization perception for mathematics teacher candidates.	Pre-service teachers for primary mathematics education from a university in Turkey.	Mathematics visualization perception measurement tool
(17)	Mathematical knowledge for early childhood teaching: A deep insight on how pre-service teachers prepare mathematical activities (Jatisunda et al., 2021)	To examine the early childhood education pre-service teachers preparing mathematical activities related to geometry concepts.	Pre-service teachers from early childhood Islamic education study program in Indonesia.	Task to create a mathematics activities
(18)	Experts and designated users evaluations on visual tools screencast SketchUp Make (ViToS-SUM) (Yahya et al., 2021)	To examine the validity of a learning strategy for 3D geometry using ViToS-SUM.	Experts in spatial skills and geometry thinking and students in Kazakhstan.	ViToS-SUM
(19)	Embodied task to promote spatial reasoning and early understanding of multiplication awangsa & Patahuddin, 2022)	Promoting spatial reasoning and developing early understanding of multiplication on students using embodied mathematics tasks.	Eight students of year 2, year 3 and year 4 from a primary school in Indonesia	Embodied spatial tasks
(20)	DOES Sketchup Make improve students' visual-spatial skills? (Abdullah et al., 2022)	To develop 3D geometry teaching strategy using SketchUp 3D geometry and investigate the effect on students' visual-spatial skills (VSS)	Junior high school students in Malaysia.	3D geometry teaching strategies through SketchUp
(21)	A virtual manipulative to support rural students in developing spatial skills in online distance education: Isometric drawing tool (Eroğlu, 2023)	To investigate the influence of learning activities using isometric drawing tool students' spatial skills in rural areas during distance education.	The 7th grade students from junior high school students in Turkey.	Isometric drawing tool
(22)	Examining the spatial abilities of 6th grade students in a computer-based instruction (Öztürk & Yilmaz, 2023)	To examine the students' spatial abilities through VPC in a GeoGebra.	The 6th grade students from four secondary schools in Turkey.	VPC in a computer-based environment
(23)	Evaluating a hypothetical learning trajectory for nets of rectangular prisms: A teaching experiment (Camci et al., 2024)	To test the effectiveness of learning trajectory in enhancing students' understanding of rectangular prism nets.	The 6th grade students from a public school in Turkey.	HLT

Table 4. The benefit of implementing spatial learning

Benefits obtained (the improvement of)	Codes of studies
Mathematics achievements	(1), (2), (12), (19)
Problem-solving skills	(2), (9), (19)
Reasoning skills	(2), (6), (8), (13), (14), (19), (20), (22)
Mathematical communication	(7), (10), (17)
Geometrical thinking (van Hiele's geometric thinking)	(5), (18)
Spatial visualization skills	(3), (4), (5), (12), (14), (15), (16), (18), (20), (21), (22)
Spatial orientation skills	(13), (20), (22)
Conceptual understanding	(8), (11), (15), (17), (19), (20), (23)

Note. Codes of studies are taken from **Table 1**

RQ3. What Are the Benefits of Implementing Spatial Learning in Mathematics Education?

The examination of the obtained articles revealed that the introduction of spatial learning in Asia yielded favorable outcomes for teachers and students equally. **Table 4** presents the benefits that the participants of the compiled studies obtained by incorporating spatial learning.

Based on analysis from collected articles, eight aspects positively influenced by the implementation of spatial learning, as shown in **Table 2**. Studies showed spatial visualization skills were mostly infected by the spatial intervention followed by reasoning skills (including spatial reasoning) and conceptual understanding. Additionally, the analysis of all collected studies indicates that spatial learning has an interconnected relationship with all variables, rather than merely influence in a single direction. Spatial visualization has proven to support the students' geometrical thinking. Implementing spatial learning using the SketchUp Make application gave students opportunities to use their ideas and strategies in learning geometry that will elevate students' geometry thinking (Wahab et al., 2017; Yahya et al., 2021).

DISCUSSION

Based on the outcomes and trends observed over the past decade, the extent of spatial-related research conducted in Asian countries was still limited. Despite the rich culture in Asian countries, only 1 over 23 gathered articles that used the implementation of the culture into learning activities (Cakmak et al., 2014), while the rest of the studies focused on the use of spatial-embedded-applications and spatial learning instructions. All the gathered studies focused on implementing spatial learning to enhance performance in geometry-related areas. However, only 13% of the 23 collected studies implemented spatial abilities apart from geometry. This is in accordance with research that demonstrated that spatial abilities have a beneficial effect on students' numerical abilities (Sinclair et al., 2018) and arithmetic (Zhang & Lin, 2017). Only six Asian countries conducted this study, with a restricted amount of research. This suggests that spatial thinking is still an overlooked aspect of learning in Asia. Although there has been research examining the beneficial impacts of incorporating spatial thinking into school curricula, the continued disregard for spatial thinking in these curricula is worrisome. Learning science, mathematics, and social studies should ideally have a strong focus on spatial activities. For instance, middle school science textbooks usually include approximately one image per page (Newcombe, 2013). Integrating embedded spatial training into school scientific curricula, namely in STEM-related disciplines, has the potential to improve students' spatial thinking abilities (Plummer et al., 2022). Another fascinating aspect of this study is the range of participants encompassed in the collected studies. The participants in the studies comprised individuals from various educational levels and professions, with the exception of senior high school students, who were not included in any of the studies. These findings may offer interesting subjects for further investigation in the domain of spatial learning.

CONCLUSION

The present study provides a thorough examination of the application of spatial learning in Asia from 2014 to early 2024. This study presents data on learning methodologies, technologies, and the advantages of incorporating spatial-oriented learning in Asia. Over the past decade, researchers have mostly focused on three primary topics: spatial learning applications, spatial embedded tasks, and instructional methodologies. Results show that despite the rich culture in Asian countries, only one study used culture-related activities to implement spatial learning, most of the studies conducted focused on the use of spatial-embedded technologies and spatial learning intervention to help students learn mathematics. However, despite the restricted research database utilized in this study, the results may provide significant insights for researchers to conduct more investigations and address the identified problems.

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Ethics declaration: This study did not require an ethics committee approval because it did not involve any human subjects and only involved the use of publicly available data or already-collected data that is fully anonymized.

Declaration of interest: Authors declare no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

REFERENCES

Abdullah, A. H., Wahab, R. A., Mokhtar, M., Atan, N. A., Halim, N. D. A., Surif, J., Zaid, N. M., Ashari, Z. M., Ibrahim, N. H., Kohar, U. H. A., Hamzah, M. H., & Rahman, S. N. S. A. (2022). DOES Sketchup Make improve students' visual-spatial skills? *IEEE Access, 10*, 13936–13953. https://doi.org/10.1109/ACCESS.2022.3147476

Abidin, Z. (2018). Mathematical communication characteristics of pre-service primary school teacher in explaining the area of trapezoid reviewed from school origin. *Journal of Research and Advances in Mathematics Education, 3*(2), 118–126. https://doi.org/10.23917/jramathedu.v3i2.6784

Bognar, B., Matic, L. J., & Sablic, M. (2024). Professional development interventions for mathematics teachers: A systematic review. *Mathematics Teaching Research Journal, 15*(6), 39–58.

Cakmak, S., Isiksal, M., & Koc, Y. (2014). Investigating effect of origami-based instruction on elementary students' spatial skills and perceptions. *The Journal of Educational Research, 107*(1), 59–68. https://doi.org/10.1080/00220671.2012.753861

Camci, F., Eroglu, D., & Tanisli, D. (2024). Evaluating a hypothetical learning trajectory for nets of rectangular prisms: A teaching experiment. *The Journal of Educational Research, 117*(1), 12–26. https://doi.org/10.1080/00220671.2024.2303505

Casey, B. M., & Fell, H. (2018). Spatial reasoning: A critical problem-solving tool in children's mathematics strategy tool-kit. In K. S. Mix, & M. T. Battista (Eds.), *Visualizing mathematics: The role of spatial reasoning in mathematical thought* (pp. 47–75). Springer. https://doi.org/10.1007/978-3-319-98767-5_3

Chang, K.-E., Wu, L.-J., Lai, S.-C., & Sung, Y.-T. (2016). Using mobile devices to enhance the interactive learning for spatial geometry. *Interactive Learning Environments, 24*(4), 916–934. https://doi.org/10.1080/10494820.2014.948458

Clements, D. H., & Sarama, J. (2020). *Learning and teaching early math: The learning trajectories approach*. Routledge. https://doi.org/10.4324/9781003083528

Davis, B. (2015). *Spatial reasoning in the early years: Principles, assertions, and speculations*. Routledge. https://doi.org/10.4324/9781315762371

Eroğlu, D. (2023). A virtual manipulative to support rural students in developing spatial skills in online distance education: Isometric drawing tool. *Journal of Necmettin Erbakan University Ereğli Faculty of Education, 5*(Special Issue), 153–190.

Hartatiana, Darhim, & Nurlaelah, E. (2017). Student's spatial reasoning through model eliciting activities with Cabri 3D. *Journal of Physics: Conference Series, 895*, Article 012075. https://doi.org/10.1088/1742-6596/895/1/012075

Hwang, W.-Y., Purba, S. W. D., Liu, Y., Zhang, Y.-Y., & Chen, N.-S. (2019). An investigation of the effects of measuring authentic contexts on geometry learning achievement. *IEEE Transactions on Learning Technologies, 12*(3), 291–302. https://doi.org/10.1109/TLT.2018.2853750

Ilhan, A., & Tutak, T. (2021). A scale development study intended for mathematics teacher candidates: Mathematical visualization perception scale. *International Electronic Journal of Mathematics Education, 16*(1), Article em0623. https://doi.org/10.29333/iejme/9578

Jatisunda, G. M., Hidayanti, M., Lita, Salim Nahdi, D., Cahyaningsih, U., & Suciawati, V. (2021). Mathematical knowledge for early childhood teaching: A deep insight on how pre-service teachers prepare mathematical activities. *Journal of Physics: Conference Series, 1778*, Article 012017. https://doi.org/10.1088/1742-6596/1778/1/012017

Khairunnisak, C., Elizar, E., Johar, R., & Utami, T. P. (2018). Teachers' use of learning resources in spatial learning. *Journal of Physics: Conference Series, 1088*, Article 012035. https://doi.org/10.1088/1742-6596/1088/1/012035

Kuit, V. K., & Osman, K. (2021). CHEMBOND3D e-module effectiveness in enhancing students' knowledge of chemical bonding concept and visual-spatial skills. *European Journal of Science and Mathematics Education, 9*(4), 252–264. https://doi.org/10.30935/scimath/11263

Lakin, J. M., Wai, J., Olszewski-Kubilius, P., Corwith, S., Rothschild, D., & Uttal, D. H. (2024). Spatial thinking across the curriculum: Fruitfully combining research and practice. *Gifted Child Today, 47*(3), 170–177. https://doi.org/10.1177/10762175241242722

Lowrie, T., Harris, D., Logan, T., & Hegarty, M. (2021). The impact of a spatial intervention program on students' spatial reasoning and mathematics performance. *The Journal of Experimental Education, 89*(2), 259–277. https://doi.org/10.1080/00220973.2019.1684869

Methley, A. M., Campbell, S., Chew-Graham, C., McNally, R., & Cheraghi-Sohi, S. (2014). PICO, PICOS and SPIDER: A comparison study of specificity and sensitivity in three search tools for qualitative systematic reviews. *BMC Health Services Research, 14*(1), Article 579. https://doi.org/10.1186/s12913-014-0579-0

Montag, M., Bertel, S., de Koning, B. B., & Zander, S. (2021). Exploration vs. limitation–An investigation of instructional design techniques for spatial ability training on mobile devices. *Computers in Human Behavior, 118*, Article 106678. https://doi.org/10.1016/j.chb.2020.106678

Newcombe, N. S. (2013). Seeing relationships: Using spatial thinking to teach science, mathematics, and social studies. *American Educator, 37*(1), 26–31.

Newcombe, N. S. (2016). Thinking spatially in the science classroom. *Current Opinion in Behavioral Sciences, 10*, 1–6. https://doi.org/10.1016/j.cobeha.2016.04.010

Newcombe, N. S. (2018). Three kinds of spatial cognition. In J. T. Wixted, E. A. Phelps, & L. Davachi (Eds.), *Stevens' handbook of experimental psychology and cognitive neuroscience* (pp. 1–31). Wiley. https://doi.org/10.1002/9781119170174.epcn315

Ng, O.-L., & Chan, T. (2019). Learning as making: Using 3D computer-aided design to enhance the learning of shape and space in STEM-integrated ways. *British Journal of Educational Technology, 50*(1), 294–308. https://doi.org/10.1111/bjet.12643

Novita, R., Putra, M., Rosayanti, E., & Fitriati, F. (2018). Design learning in mathematics education: Engaging early childhood students in geometrical activities to enhance geometry and spatial reasoning. *Journal of Physics: Conference Series, 1088*, Article 012016. https://doi.org/10.1088/1742-6596/1088/1/012016

OECD. (2023). PISA 2022 assessment and analytical framework. *Organization for Economic Co-operation and Development.* https://www.oecd-ilibrary.org/fr/education/pisa-2022-assessment-and-analytical-framework_dfe0bf9c-en

Öztürk, O., & Yilmaz, R. (2023). *Examining the spatial abilities of 6th grade students in a computer-based instruction* [Paper presentation]. International Eurasian Educational Research Congress.

Patahuddin, S. M., Ramful, A., Lowrie, T., & Bholoa, A. (2022). Subtleties in spatial visualization maneuvers: Insights from numerical solutions. *The Journal of Mathematical Behavior, 67*, Article 100988. https://doi.org/10.1016/j.jmathb.2022.100988

Patahuddin, S. M., Rokhmah, S., & Ramful, A. (2020). What does teaching of spatial visualization skills incur: An exploration through the visualize-predict-check heuristic. *Mathematics Education Research Journal, 32*(2), 307–329. https://doi.org/10.1007/s13394-020-00321-2

Plummer, J. D., Udomprasert, P., Vaishampayan, A., Sunbury, S., Cho, K., Houghton, H., Johnson, E., Wright, E., Sadler, P. M., & Goodman, A. (2022). Learning to think spatially through curricula that embed spatial training. *Journal of Research in Science Teaching, 59*(7), 1134–1168. https://doi.org/10.1002/tea.21754

Pradana, L. N., Sa'dijah, C., Sulandra, I. M., Sudirman, & Sholikhah, O. H. (2020). Virtual mathematics kits (VMK): The value of spatial orientation on it. *European Journal of Educational Research, 9*(3), 1105–1114. https://doi.org/10.12973/eu-jer.9.3.1105

Putrawangsa, S., & Patahuddin, S. (2022). *Embodied task to promote spatial reasoning and early understanding of multiplication* [Paper presentation]. Annual Meeting of the Mathematics Education Research Group of Australasia.

Putri, R. O. E. (2018). Spatial skill profile of mathematics pre-service teachers. *Journal of Physics: Conference Series, 947*, Article 012065. https://doi.org/10.1088/1742-6596/947/1/012065

Ramey, K. E., Stevens, R., & Uttal, D. H. (2020). In-FUSE-ing STEAM learning with spatial reasoning: Distributed spatial sensemaking in school-based making activities. *Journal of Educational Psychology, 112*, 466–493. https://doi.org/10.1037/edu0000422

Ramful, A., Lowrie, T., & Logan, T. (2017). Measurement of spatial ability: Construction and validation of the spatial reasoning instrument for middle school students. *Journal of Psychoeducational Assessment, 35*(7), 709–727. https://doi.org/10.1177/0734282916659207

Ramful, A., Maesuri Patahuddin, S., Moheeput, K., & Johar, R. (2023). The spatial requirements of the left-hand rule: A novel instrument for assessing the coordination of egocentric and allocentric frames of reference. *International Journal of Science Education, 45*(8), 661–687. https://doi.org/10.1080/09500693.2023.2172625

Santrock, J. W. (2017). *Educational psychology.* McGraw-Hill Education.

Sinclair, N., Moss, J., Hawes, Z., & Stephenson, C. (2018). Learning through and from drawing in early years geometry. In K. S. Mix, & M. T. Battista (Eds.), *Visualizing mathematics: The role of spatial reasoning in mathematical thought* (pp. 229–252). Springer. https://doi.org/10.1007/978-3-319-98767-5_11

Slavin, R. E. (2018). *Educational psychology: Theory and practice*. Pearson.

Tsai, C.-H., & Yen, J.-C. (2014). Teaching spatial visualization skills using OpenNI and the Microsoft Kinect Sensor. In J. Park, Y. Pan, C. S. Kim, & Y. Yang (Eds.), *Future information technology. Lecture notes in electrical engineering, vol 309* (pp. 617–624). Springer. https://doi.org/10.1007/978-3-642-55038-6_97

Tsai, C.-H., Kuo, Y.-H., Chu, K.-C., & Yen, J.-C. (2015). Development and evaluation of game-based learning system using the Microsoft Kinect Sensor. *International Journal of Distributed Sensor Networks, 11*(7), Article 498560. https://doi.org/10.1155/2015/498560

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: A meta-analysis of training studies. *Psychological Bulletin, 139*, 352–402. https://doi.org/10.1037/a0028446

Wahab, R. A., Abdullah, A. H., Mokhtar, M., Atan, N. A., & Abu, M. S. (2017). Evaluation by experts and designated users on the learning strategy using Sketchup Make for elevating visual spatial skills and geometry thinking. *Bolema-Mathematics Education Bulletin, 31*(58), 819–840. https://doi.org/10.1590/1980-4415v31n58a15

Wai, J., & Uttal, D. H. (2018). Why spatial reasoning matters for education policy. *American Enterprise Institute*. https://www.aei.org/research-products/report/why-spatial-reasoning-matters-for-education-policy/

Yahya, F. H., Kassymova, G. K., Murtafiah, W., & Suparman, S. (2021). Experts and designated users evaluations on visual tools screencast SketchUp Make (ViToS-SUM). *Perspektivy Nauki i Obrazovania, 54*(6), 460–472. https://doi.org/10.32744/pse.2021.6.31

Yurt, E., & Sünbül, A. M. (2014). A structural equation model explaining 8^{th} grade students' mathematics achievements. *Educational Sciences: Theory and Practice, 14*(4), 1642–1652. https://doi.org/10.12738/estp.2014.4.2193

Zhang, X., & Lin, D. (2017). Does growth rate in spatial ability matter in predicting early arithmetic competence? *Learning and Instruction, 49*, 232–241. https://doi.org/10.1016/j.learninstruc.2017.02.003