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Bibliometric Analysis of Spatial Ability Studies Based on Scopus Data

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Abstract

The aim of this study was to conduct a bibliometric analysis of all studies related to spatial ability available in the Scopus database. It is expected that this research will make a significant contribution to the literature on spatial ability and serve as an important resource. In this way, researchers can gain a better understanding of the topic, evaluate the current research landscape, and use this information to plan their own studies. A bibliometric analysis method was employed in this study. Through this method, the Scopus database was searched, and 7,345 studies published from 1939 to the present were examined. We categorized the selected studies by publication year, source, authors, institutions, countries, types, subject areas, and the most highly cited works. Additionally, network maps illustrating co-authorship relationships by author and country, common keyword networks, bibliographic coupling by institution, and co-citation networks based on cited studies, journals, and authors are presented in detail in the findings section. The results indicate that numerous studies on various aspects of spatial ability have been conducted in different countries over time.

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Introduction

Mathematics education is central to the educational process because mathematics is a discipline that develops individual inquiry, analytical, and critical thinking skills. Mathematical concepts guide individuals to think logically and systematically when faced with complex situations. Additionally, by strengthening problem-solving abilities, mathematics enables individuals to develop diverse perspectives, thus contributing to more informed and effective decision-making in various areas of life (Günhan, 2006). Consequently, mathematics plays a significant role in nearly every aspect of life; therefore, mathematics education should be optimally structured and implemented (Kaçar, 2019:2).

Recent changes and developments in the field of learning have led to significant shifts in perspectives on mathematics and mathematics education. The foundation of this change is the notion that the purpose of education is not only to produce individuals who possess knowledge but also to cultivate those who have the ability to learn, conduct inquiry, ; critically, and adapt to these innovations effectively (MEB, 2018a). Learning mathematics is not limited to acquiring basic concepts and skills. It also involves understanding thought processes related to mathematics, learning strategies, and recognizing the importance of mathematics as a vital requirement in daily life (MEB, 2005). Because of its abstract nature, mathematics can pose difficulties for students in learning the subject. It has been observed that traditional teaching methods do not fully develop mathematical knowledge and skills. Therefore, it is important to revise and update these approaches according to current conditions through examination and analysis (MEB, 2018b). When necessary innovations are made, students can perceive abstract concepts in a more concrete manner and better assimilate their learning in their minds.

One of the important abstract concepts in mathematics is geometry, which also holds significant importance in our lives by contributing to our thought processes and enabling logical inferences (Birni & Karadağ, 2016). Geometry is a fundamental skill that fosters active thinking, communication, and problem-solving and interpretative abilities (Terzi, 2010). The primary aim of geometry instruction is to equip students with geometric thinking skills, thereby enhancing their creative and critical thinking skills, strengthening their ability to make predictions, and enabling them to make connections with various areas of mathematics. Furthermore, geometry education aims to develop spatial thinking skills by helping individuals understand spatial relationships, mentally manipulate objects, and solve both mathematical problems and everyday questions more effectively (MEB, 2010; Tüzün ve Cihangir, 2020).

Individuals with advanced spatial awareness can notice and examine geometric structures and patterns in their environments. They possess the ability to perceive, explain, and analyze what they see using perspectives

associated with geometry (Durmuş, 2021). Additionally, spatial ability is considered a fundamental skill for learning mathematics and geometry. Numerous studies have revealed a positive correlation between spatial and mathematical thinking abilities (e.g., Guay & McDaniel, 1977; Kösa, 2011; Tartre, 1990). Similarly, spatial ability is not only crucial for achieving success in learned subjects and is also an important and necessary skill in many areas of life. According to researchers, spatial ability plays a significant role in the development of societies with high levels of well-being and advanced living conditions, as well as in the emergence of necessary innovations (Özyaprak, 2012). Therefore, many studies have been conducted on this topic and continue to be conducted (e.g., Maeda & Yoon, 2013, 2013; Techentin et al., 2014; Xie et al., 2020).

There is substantial research indicating that spatial thinking ability can be developed through education. It has been noted that this ability can be enhanced through applications in fields such as engineering and architecture, including drawings and computer applications. Traditionally, efforts to improve spatial ability have primarily focused on university students and have been conducted through engineering and architecture programs. However, contemporary research has explored how such efforts can be adapted to lower educational levels, particularly for elementary school students. Some researchers have emphasized the importance of interacting with concrete objects to enhance spatial visualization, especially for primary and secondary school students (Werthessen 1999; Melancon 1994; Bennie and Smith 1999; Battista 1989; Gutierrez 1992; Battista and Clements, 1996; Hirstein 1981; Geddes and Fortuna 1993, cited in Olkun et al., 2014; Tosik-gün and Güyer, 2019).

Research on spatial ability has a long history (Lohman, 1979; Smith, 1964). Di and Zheng (2022) investigated the extent of technology's impact on spatial ability, and Maeda and Yoon (2013) explored the effects of spatial thinking in three-dimensional objects on gender differences. In another study, Xie et al. (2020) examined the relationship between spatial ability and mathematical ability, revealing a significant relationship between these two skills and highlighting that spatial ability positively influences logical reasoning.

Research provides valuable insights by revealing the current state of a field and identifying general trends. By reviewing the current literature and building upon previous research, these studies allow us to understand the discipline's status at a particular time. Additionally, they serve as a guide for researchers and academics regarding future research directions and trends, helping to identify gaps in the field and establish research priorities. Evaluating scientific research in a specific area plays a crucial role in shaping the field's trends and priorities by providing a foundation for future work (Falkingham & Reeves, 1997). Similarly, Dunkin (1996) emphasized the importance and necessity of synthesizing research qualities. The literature also indicates that there are studies examining various topics conducted in Turkey. When reviewing the literature on spatial ability, numerous studies have been conducted on this topic from the past to the present (Güven & Kosa, 2008;

Hendroanto et al., 2015; Lean & Clements, 1981; Olkun, 2003; Sutton & Williams, 2007; Tartre, 1990; Yıldız & Tüzün, 2011). However, a bibliometric analysis of articles published on spatial ability in Scopus has not yet been performed.

Therefore, this study aimed to conduct a bibliometric analysis of research on spatial ability based on the Scopus database. It is anticipated that this study will contribute to the literature on spatial ability and provide a comprehensive review of existing studies on the topic. This will help researchers plan their spatial abilities to observe, understand, and evaluate the current state of the field, thereby assisting them in planning their own research. The subproblems formulated within this scope are outlined below.

In the Scopus database, how is the distribution of studies on spatial ability characterized by the following categories: year, source, author, institution, country, type, subject area, and most cited works?
What does the network map look like regarding: co-authorship relationships by authors, co-authorship relationships by countries, co-occurrence of keywords, bibliography matching by institutions, co-citations of cited works, cited journals, and co-citations of cited authors?

Method

Research Design

This study aimed to conduct a bibliometric analysis of research on spatial ability based on the Scopus database. Bibliometric analysis, as used in this study, involves analyzing and examining scientific articles on various topics, their authors, and numerous other written sources (Broadus, 1987). Bibliometric analysis is an analysis technique used to evaluate the literature, which includes studies in the relevant field (books, book chapters, articles, early access publications that have not yet been published) (Mutluer, 2023).

It also provides visual maps of the interconnections between highly cited sections, the most prolific and influential authors, scientific journals, and countries related to the research topics (Kurutkan & Orhan, 2018). Through bibliometric analysis, it is possible to examine and analyze the collaborations between authors, institutions, and countries, as well as the relationships among keywords in published works on the relevant topic. Utilizing bibliometric analysis helps review the work of expert researchers in the field, evaluate their performance, and track developments in a specific topic or journal. Additionally, it supports and contributes to the development of scientifically accepted decisions in the literature. Such analyses provide valuable information about the originality and rigor of the reviewed studies (Ukşul, 2016). Based on this information, analyses using tables (by publication years, sources, authors, connections, countries, types, subject areas) and

scientific field mapping (co-authorship, co-occurrence of keywords, bibliography matching, and co-citation) have been conducted as part of the bibliometric data analysis steps.

Data Collection

In accordance with the aim of the study, research on spatial ability in the literature was examined using bibliometric analysis of studies published in the Scopus database. Scopus is described as "the largest single abstract and indexing database ever created," indexing over 14,000 titles from 4,000 publishers. The database contains 27 million abstracts extending back to 1966, including 100% coverage of MEDLINE, EMBASE, and Compendex. It encompasses literature from both English and other languages and covers Europe and the Asia-Pacific region. Scopus links cited and citing documents, indexes open-access titles, and includes over 167 million web pages and patents. It is OpenURL-compliant, performs access control for full-text access, and links to publisher sites. Scopus claims 99% citation accuracy, provides COUNTER-compliant usage reports, and offers various training options and technical support (Burnham, 2006).

In the bibliometric analysis, a literature review was conducted based on predetermined questions to identify studies that were suitable for inclusion. According to this review, studies available in Scopus were selected. During the data collection process, the content of these studies was analyzed, and experts in the field were consulted to select relevant keywords. Based on the feedback received, research was conducted using the identified keywords. The literature was examined using search terms such as "spatial thinking," "spatial ability," "spatial visualization," "spatial think* skill*," and "spatial visualization skill*," focusing on studies that included these terms in their titles, keywords, or abstracts. All studies from the past to the present, across all indices, document types, publishers, institutions, authors, languages of publication, and Scopus categories, were included in the search, resulting in the identification of 7,345 studies. These studies were exported, and the analysis phase was initiated.

Data Analysis

VOSviewer is a powerful software tool for bibliometric analysis and scientific mapping. Researchers favor this tool for visualizing and analyzing the relationships between academic publications and citations. VOSviewer is particularly useful for mapping connections between publications, coauthorship relationships, keyword clusters, and citation networks. The user-friendly interface facilitates data loading, preprocessing, and visualization with ease. The software can handle large datasets and presents results in colorful, interactive maps, enabling researchers to easily identify patterns and trends in the data. VOSviewer is an important tool for assessing scientific impact and understanding the dynamics of research fields (Arruda et al., 2022).

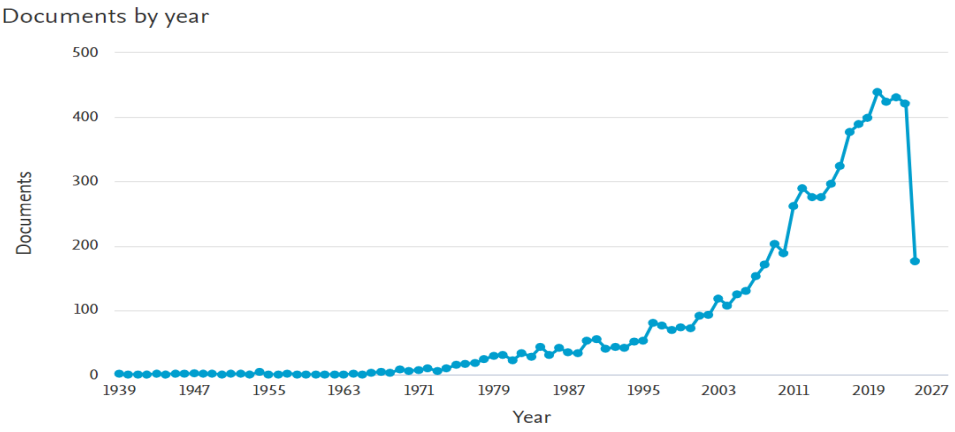
In this study, the Scopus database was used, and maps were created and analyzed using the bibliometric mapping feature of VOSviewer for the analyses. Findings related to predetermined questions for selected studies in Scopus were directly tabulated from the database. Thus, both tabular analyses from Scopus and bibliometric analyses were conducted using VOSviewer and interpreted. The obtained results are detailed in the finding section.

Validity and Reliability of the Study

In this bibliometric analysis research, the literature review, identification, and selection of relevant studies, formulation of core problems related to the topic, examination of selected studies under consistent headings, synthesis, and reporting are presented in detail. The objectives of this research and the problems defined for this study are clearly and explicitly presented. Ensuring the validity of the examined and synthesized studies is crucial for reliability. Therefore, to minimize errors, the selected studies were exported and thoroughly reviewed over an extended period. Consultations were conducted with experts in the field, and a consensus was reached before analyzing the obtained information.

Findings

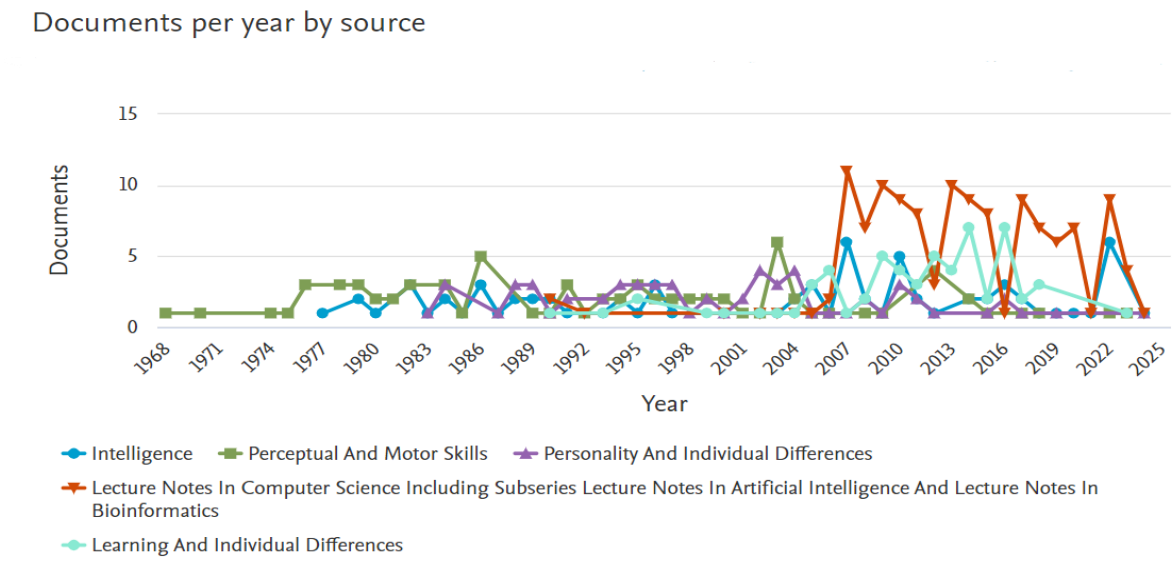
In line with the research topic, the distribution of studies in the Scopus database was examined based on publication years, sources, authors, citations, countries, types, and subject areas. Subsequently, network analyses were conducted to examine co-authorship (authors, countries), co-occurring keywords, bibliographic coupling (authors, journals, countries), and co-citation (authors, papers, journals). The distribution of published studies on spatial ability by years is provided below.



Graph 1. Distribution of Articles by Year

As shown in Graph 1, research on spatial ability began in 1939, with a general increase in the number of studies over the years, except for recent years. It is noted that no studies (N=0) on spatial ability were conducted in certain years (1940, 1941, 1942, 1944, 1950, 1953, 1955, 1956, 1958, 1959, 1960, 1961, 1962, 1963, 1965). The highest number of studies was conducted in 2020 (N=439). Since 1974, there has been a noticeable increase in interest in the region. Despite fluctuations between years, an overall upward trend was observed. Although a decline was observed in 2024, it should be noted that the number of studies represented in the graph only covers the first five months of the year.

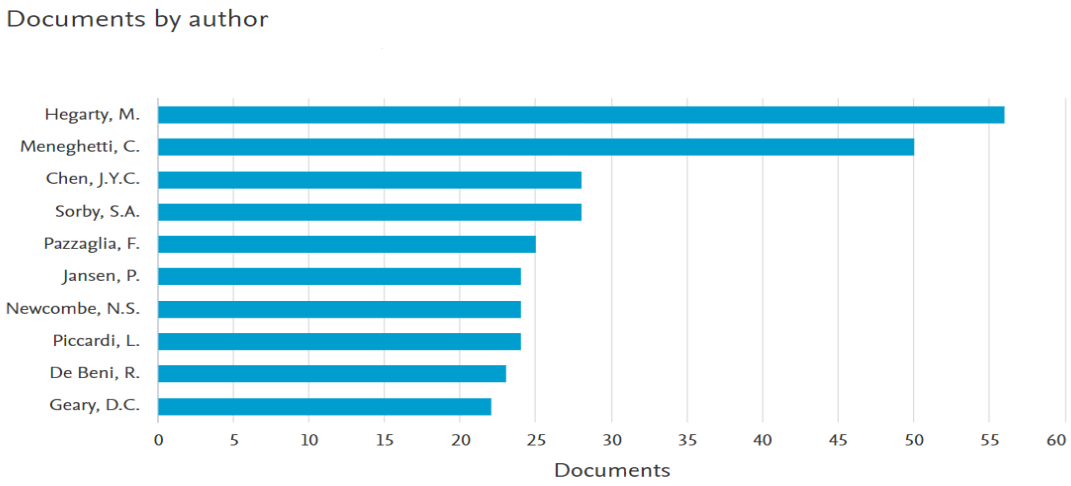
The annual distribution of spatial ability studies based on the top five sources of publication is presented below.



Graph 2. Annual Distribution of Articles by the Top 5 Sources

Graph 2 shows the distribution of studies on spatial ability across sources, with the top-ranked source being the journal Lecture Notes in Computer Science, including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics (N=130). This is followed by Intelligence (N=77), Perceptual and Motor Skills (N=77), Personality and Individual Differences (N=63), and Learning and Individual Differences (N=62). The journal Lecture Notes in Computer Science, including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics, has published relevant studies since 1990. Intelligence has been published from 1978 to the present, Perceptual and Motor Skills from 1968 to 2023, Personality and Individual Differences from 1984 to the present, and Learning and Individual Differences from 1990 to 2023.

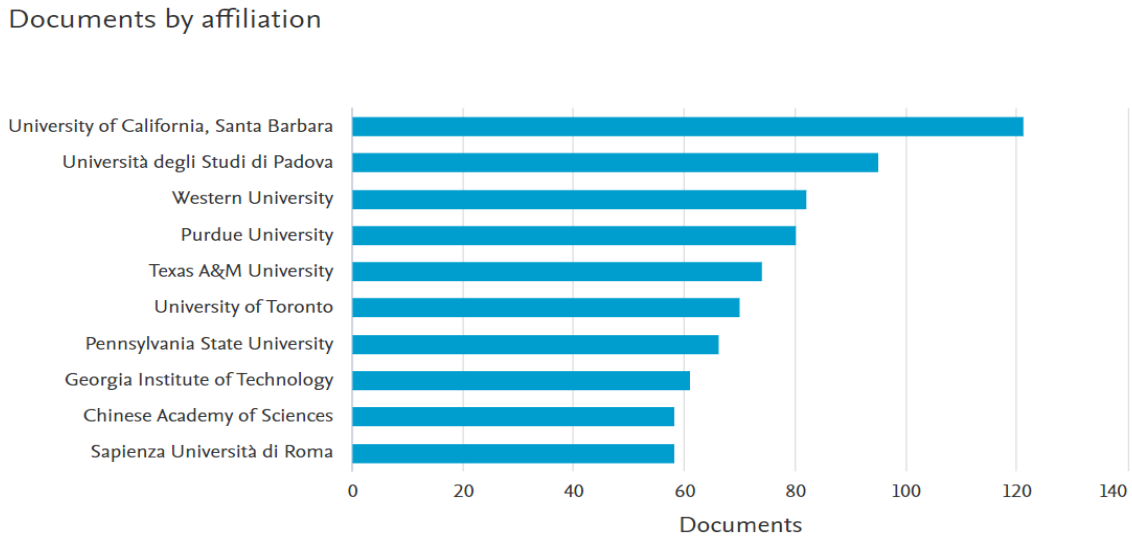
The distribution of studies on spatial ability by the top 10 authors and most published papers is presented below.



Graph 3. Distribution of the Top 10 Authors with the Most Publications

Graph 3 shows that the author of the most studies on spatial ability is M. Hegarty (N=56). C. Meneghetti (N=50), J.Y.C. Chen (N=28), S.A. Sorby (N=28), F. Pazzaglia (N=25), P. Jansen (N=24), N.S. Newcombe (N=24), L. Piccardi (N=24), R. De Beni (N=23), and D.C. Geary (N=22) follow.

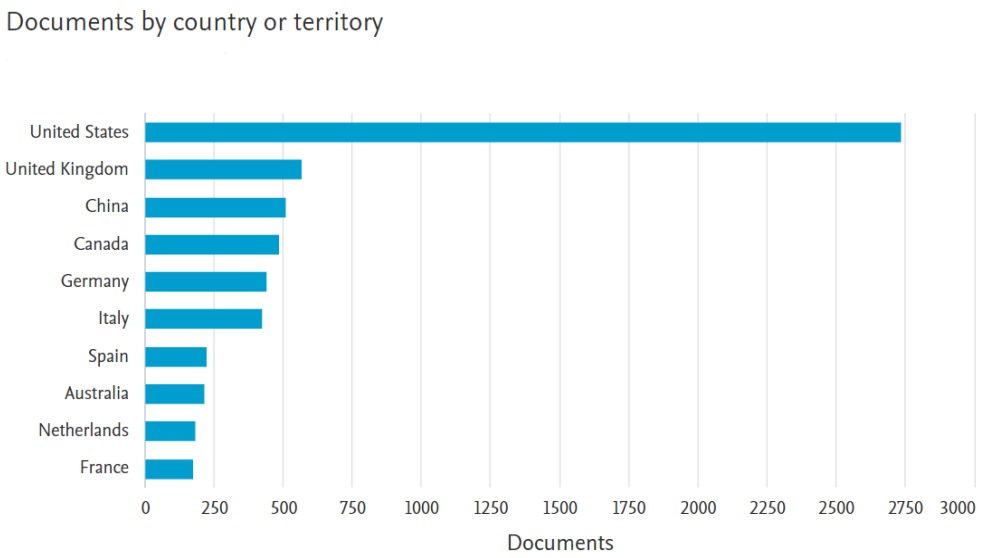
The distribution of spatial ability studies by the top 10 institutions is provided below.



Graph 4. Distribution of Studies by Top 10 Institutions

Graph 4 shows that the institution with the highest number of studies on spatial ability is the University of California (N=121). This was followed by Università degli Studi di Padova (N=95), Western University (N=82), Purdue University (N=80), Texas A&M University (N=74), University of Toronto (N=70), Pennsylvania State University (N=66), Georgia Institute of Technology (N=61), Chinese Academy of Sciences (N=58), and Sapienza Università di Roma (N=58).

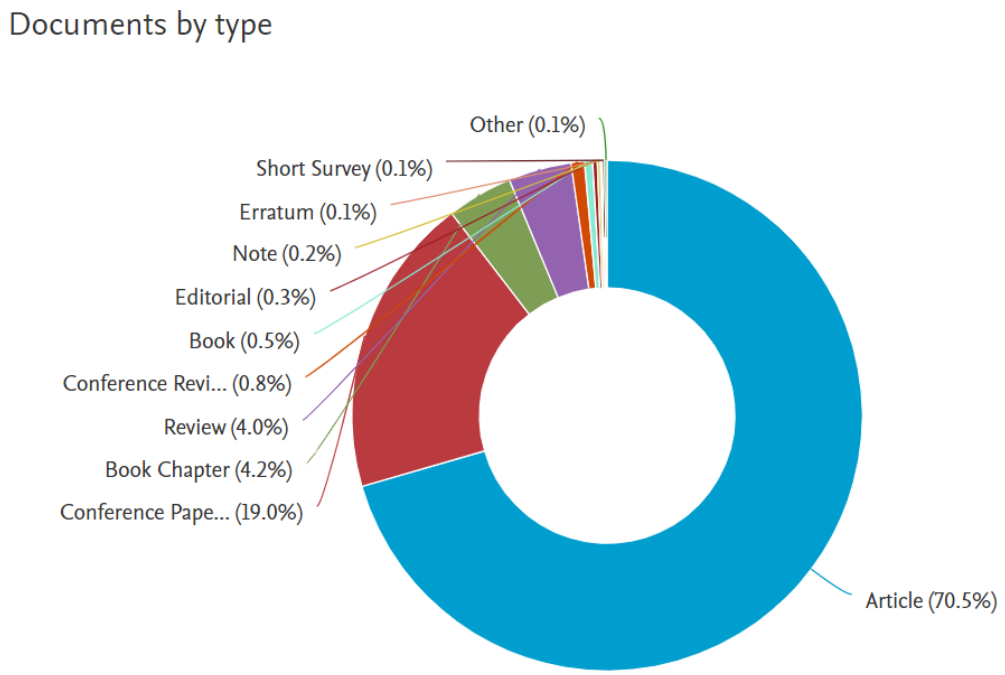
The distribution of studies on spatial ability by the top 10 countries is provided below.



Graph 5. Distribution of Studies by Top 10 Countries

Graph 5 shows that the country with the highest number of studies on spatial ability is the United States (N=2,732). This is followed by the United Kingdom (N=566), China (N=506), Canada (N=483), Germany (N=437), Italy (N=423), Spain (N=221), Australia (N=211), the Netherlands (N=180), and France (N=172).

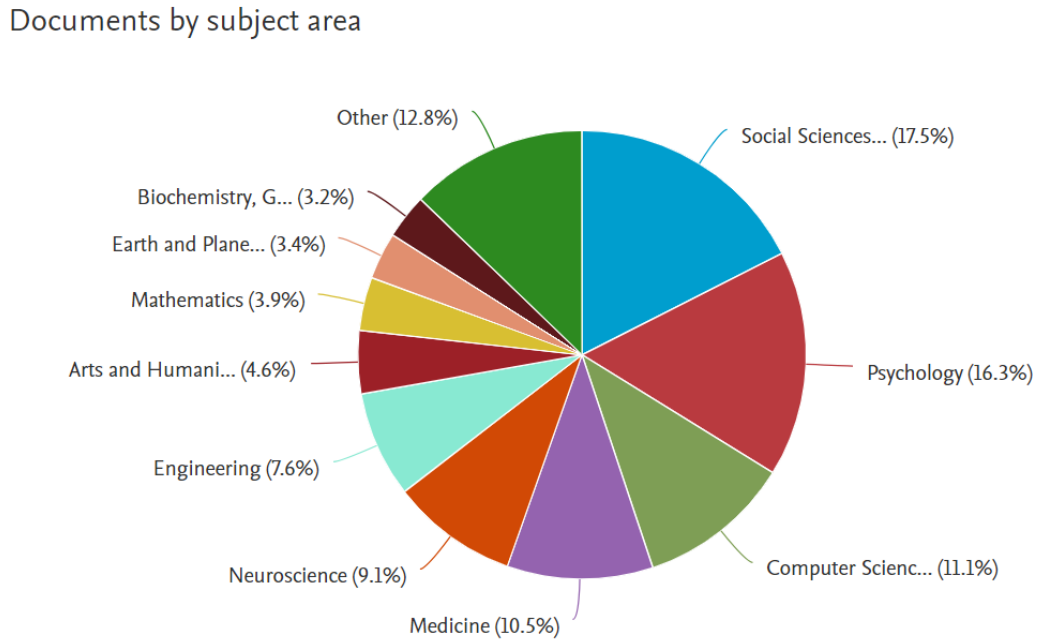
The distribution of studies on spatial ability by type is presented below.



Graph 6. Distribution of Studies by Type

Graph 6 shows that the most common type of publication on spatial ability is a journal article (N=5,181). This is followed by conference proceedings (N=1,398), book chapters (N=306), reviews (N=293), conference reviews (N=62), books (N=38), editorials (N=22), notes (N=14), corrections (N=10), and other types (N=21).

The distribution of studies on spatial ability by subject area is provided below.



Graph 7. Distribution of Studies by Subject Area

Graph 7 shows that the leading subject area for studies on spatial ability is Social Sciences (N=2,319). This is followed by Psychology (N=2,152), Computer Science (N=1,467), Medicine (N=1,391), Neuroscience (N=1,209), Engineering (N=1,011), Arts and Humanities (N=602), Mathematics (N=510), Earth and Planetary Sciences (N=446), Biochemistry, Genetics and Molecular Biology (N=428), and other categories (N=1,690).

The distribution of the top five most-cited studies on spatial ability published in the Scopus database is presented below.

Table 1. Distribution of the Top Five Most-Cited Works in the Scopus Database

	Belge başlığı	Yazarlar	Kaynak	Yıl	Alıntılar
1	Article **Neurocognitive deficit in schizophrenia: A quantitative review of the evidence** Show abstract Full Text View at Publisher Related documents	Heinrichs, R.W., Zakzanis, K.K.	Neuropsychology, 12(3), pp. 426–445	1998	2,375
2	Article **Emergence and characterization of sex differences in spatial ability: a meta-analysis.** Show abstract Full Text View at Publisher	Linn, M.C., Petersen, A.C.	Child development, 56(6), pp. 1479–1498	1985	2,243
3	Article **Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables** Show abstract Full Text View at Publisher Related documents	Voyer, D., Voyer, S., Bryden, M.P.	Psychological Bulletin, 117(2), pp. 250–270	1995	2,096
4	Article **Mental rotations, a group test of three-dimensional spatial visualization** Full Text View at Publisher	Vandenberg, S.G., Kuse, A.R.	Perceptual and Motor Skills , 47(2), pp. 599–604	1978	1,927
5	Article **Mapping ecosystem service supply, demand and budgets** Show abstract Full Text View at Publisher Related documents	Burkhard, B., Kroll, F., Nedkov, S., Müller, F.	Ecological Indicators, 21, pp. 17–29	2012	1,602

Table 1 shows the type, authors, publication years, and citation counts of the top five most-cited studies on spatial ability. All five highly cited studies were journal articles. The most cited paper is "Neurocognitive Deficit in Schizophrenia: A Quantitative Review of the Evidence" (Heinrichs, R.W., & Zakzanis, K.K.), which was published in Neuropsychology in 1998 and has received 2,375 citations since its publication. This is followed by "Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis" (Linn, M.C., & Petersen, A.C.), published in Child Development in 1985, with 2,443 citations; "Magnitude of Sex Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables" (Voyer, D., Voyer, S., & Bryden, M.P.), published in Psychological Bulletin in 1995, with 2,096 citations; "Mental Rotations, A Group Test of Three-Dimensional Spatial Visualization" (Vandenberg, S.G., & Kuse, A.R.), published in Perceptual and Motor Skills in 1978, with 1,927 citations; and "Mapping Ecosystem Service Supply, Demand, and Budgets" (Burkhard, B., Kroll, F., Nedkov, S., & Müller, F.), published in Ecological Indicators in 2012, with 1,602 citations.

A network map showing co-authorship relationships among authors of studies on spatial ability is provided below.

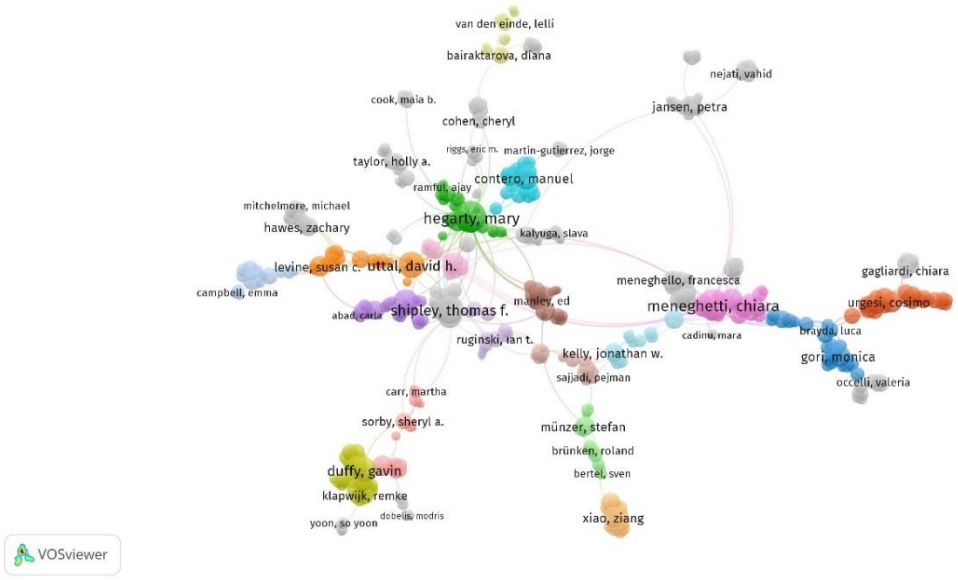


Figure 1. Coauthorship Network Map of Authors in the Studies

Figure 1 shows the co-authorship network map of the authors of the spatial ability. To identify co-authorship relationships, a minimum of two publications and two citations per author were established. Based on these criteria, the total number of authors listed in the included studies was 2,029, with 448 forming a large cluster. The analysis revealed that the largest connected group consisted of 38 clusters (number of connections: 1,086, total connection strength: 2,035). Each of these 38 clusters contains between 2 and 9 co-authors. Among these authors, Mary Hegarty (number of connections: 34, total connection strength: 69), Chiara Meneghetti (number of connections: 32, total connection strength: 124), and F. Thomas Shipley (number of connections: 26, total connection strength: 51) was a particularly prominent. A common link among these researchers is their focus on understanding how people process, represent, and utilize spatial information and tasks.

A network map showing coauthorship relationships by country for spatial ability studies is provided below.

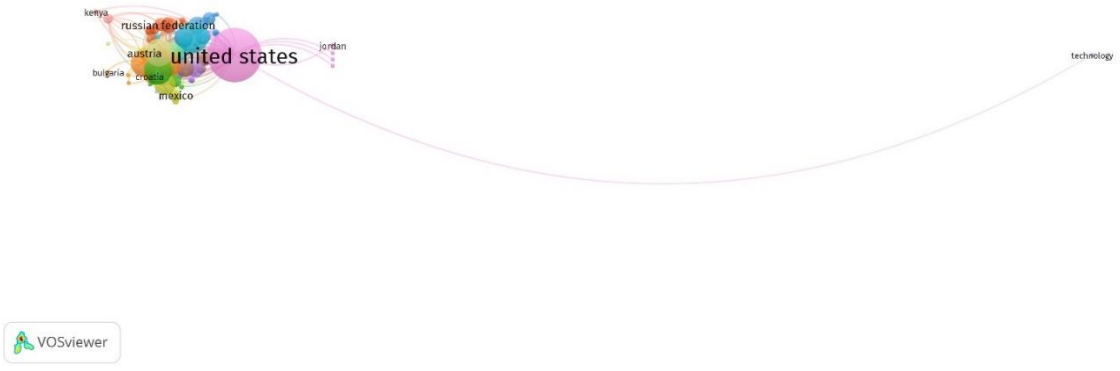


Figure 2. Co-Authorship Network Map by Country in the Studies

Figure 2 shows the coauthorship network map by country for studies on spatial ability. To identify co-authorship relationships, a minimum of two publications and two citations per author were established. Based on these criteria, the total number of countries listed in the studies was 91, with 88 countries constituting a large cluster. The analysis revealed that the largest connected group consists of 9 clusters (number of connections: 520, total connection strength: 1,639). Each of these 9 clusters contains between 2 and 9 co-authoring countries. Among these countries, the United States (number of connections: 60, total connection strength: 557), the United Kingdom (number of connections: 52, total connection strength: 309), Germany (number of connections: 47, total connection strength: 215), Canada (number of connections: 39, total connection strength: 186), Australia (number of connections: 33, total connection strength: 132), Switzerland (number of connections: 31, total connection strength: 104), the Netherlands (number of connections: 30, total connection strength: 95), France (number of connections: 29, total connection strength: 105), Italy (number of connections: 28, total connection strength: 125), and Turkey (number of connections: 26, total connection strength: 52) are particularly prominent.

A network map showing the co-occurrence of key terms in spatial ability studies is provided below.

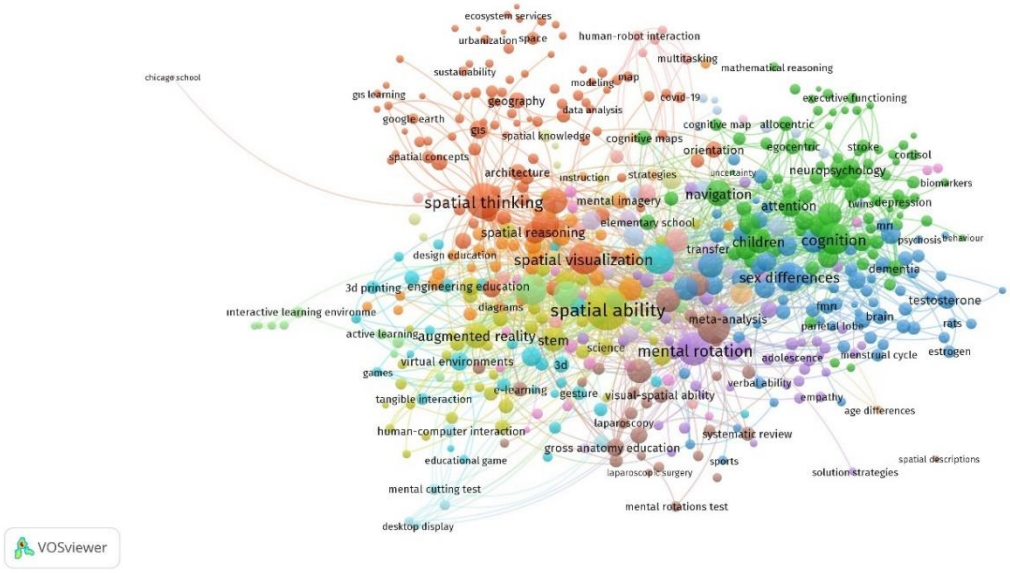


Figure 3. Co-Occurrence Network Map of Keywords in the Studies

Figure 3 shows that common key terms in spatial ability studies had a minimum co-occurrence of five. The total number of key terms was 532. The analysis revealed that the largest connected group of common key terms comprised 18 clusters (number of connections: 5,889, total connection strength: 9,915). Each of these 18 clusters contains between 5 and 44 common key terms. Among these common key terms, "spatial ability" (number of connections: 338, total connection strength: 1,435) had the highest connection strength. This was followed by "spatial thinking" (number of connections: 209, total connection strength: 506), "mental rotation"

(number of connections: 174, total connection strength: 582), "spatial visualization" (number of connections: 154, total connection strength: 350), and "cognition" (number of connections: 153, total connection strength: 363) as frequently used common key terms.

A network map showing citation matching by institutions for spatial ability studies is provided below.

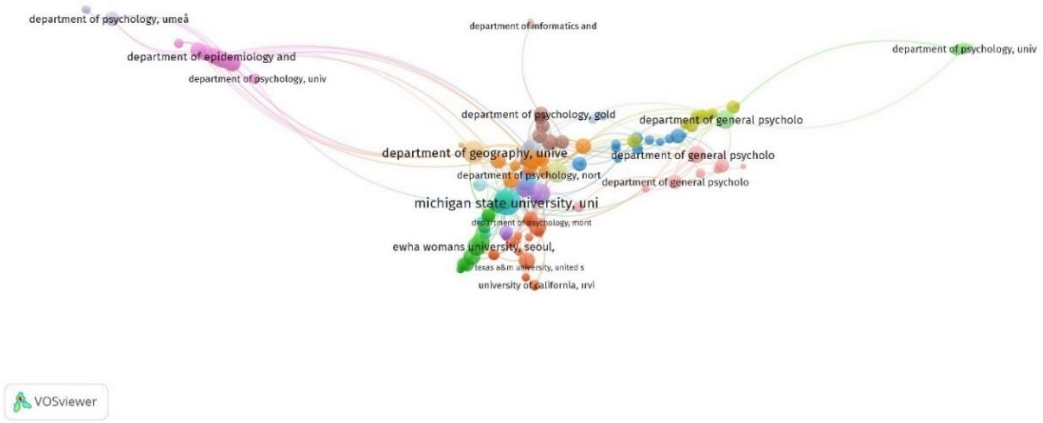


Figure 4. Bibliographic Coupling Network Map of Institutions in the Studies

Figure 4 shows that in the citation matching by institutions for studies on spatial ability, the criteria were a minimum of three publications and three citations per institution. According to these criteria, 146 out of 210 institutions met the requirements. These 146 institutions were organized into 17 clusters (number of connections: 383, total connection strength: 639). Each cluster contains between 2 and 20 institutions. Among these institutions, Michigan State University (number of connections: 33, total connection strength: 47), the University of California Santa Barbara (number of connections: 20, total connection strength: 29), Temple University (number of connections: 18, total connection strength: 23), and the University of Padua (number of connections: 14, total connection strength: 33) were particularly prominent. A network map showing the co-citation relationships of cited works in spatial ability studies is provided below.

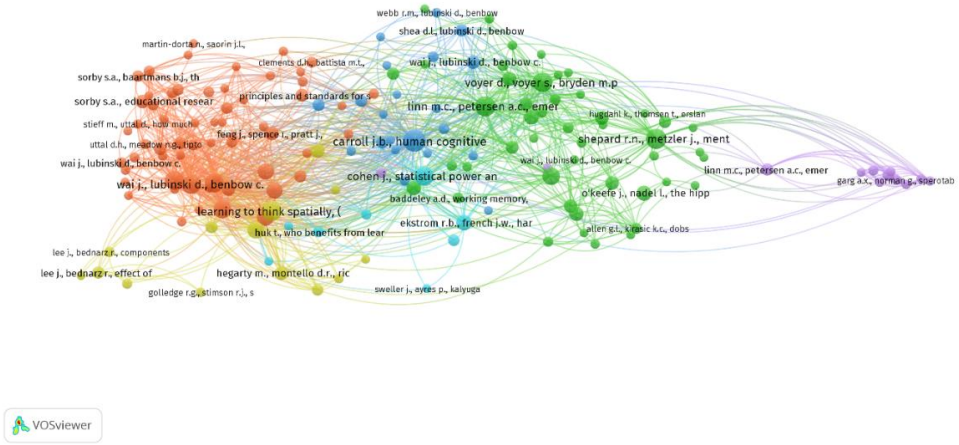


Figure 5. Co-Citation Network Map of Cited Works in Different Studies

Figure 5 shows that for spatial ability studies, the co-citation analysis of cited works was conducted with a minimum co-citation count of 20. According to this criterion, there are 199,915 cited works, of which 162 meet this criterion. The network map resulting from the analysis consists of a total of 6 clusters (number of connections: 5,212, total connection strength: 14,598), with each cluster containing between 8 and 60 cited works. The most frequently cited works in these studies are, in order: Carroll J.B., Human Cognitive Abilities: A Survey of Factor Analytic Studies (1993) (number of connections: 147, total connection strength: 907), Cohen J., Statistical Power Analysis for the Behavioral Sciences (1988) (number of connections: 130, total connection strength: 423), and Linn M.C. & Petersen, A. C. (1985). Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis (1985) (number of connections: 125, total connection strength: 703).

A network map showing the co-citation relationships of cited journals in spatial ability studies is provided below.

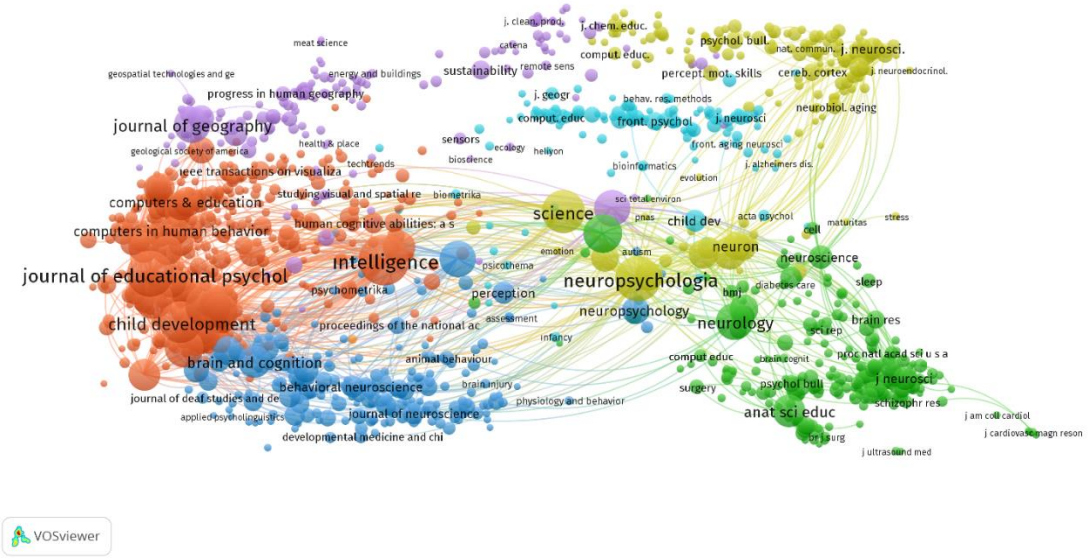


Figure 6. Co-Citation Network Map of Cited Studies

Figure 6 shows that for spatial ability studies, the co-citation analysis of cited journals was conducted with a minimum co-citation count of 20. Accordingly, 67,295 journals were cited, of which 1,330 met the criteria. The network map resulting from the analysis consists of a total of 7 clusters (number of connections: 182,047, total connection strength: 2,269,534), with each cluster containing between 1 and 403 cited journals. Among these journals, the most prominent ones are Science (number of connections: 1,288, total connection strength: 59,423), Plos One (number of connections: 1,234, total connection strength: 43,069), Nature (number of connections: 1,203, total connection strength: 40,716), Intelligence (number of connections: 1,181, total

connection strength: 83,432), Neuropsychologia (number of connections: 1,164, total connection strength: 78,585), and Cognition (number of connections: 1,116, total connection strength: 44,030).

A network map showing the co-citation relationships of cited authors in spatial ability studies is provided below.

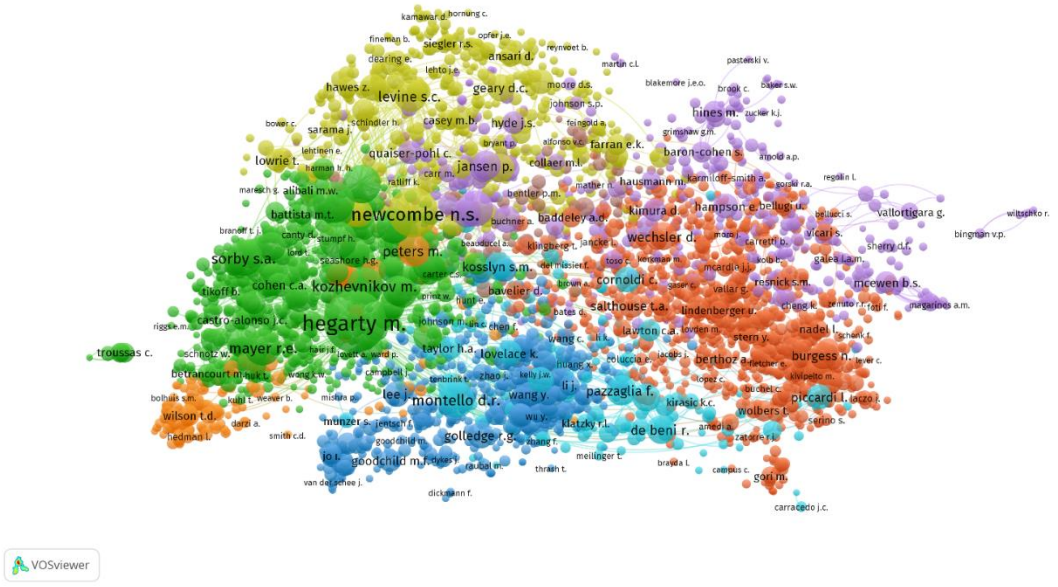


Figure 7. Co-Citation Network Map of Cited Authors in a Cross-sectional Study

Figure 7 illustrates that the minimum threshold for co-citations among cited authors in spatial ability research is set at 20. Accordingly, 238,481 authors were cited, with 3,968 meeting the established criteria. The network map comprises a total of 8 clusters (with a connection count of 1,782,387 and a total connection strength of 10,010,890), with each cluster containing between 130 and 1,172 cited authors. Among these authors, the most prominent are M. Hegarty (with 3,697 connections and a total connection strength of 287,348), N.S. Newcombe (with 3,576 connections and a total connection strength of 195,862), M.C. Linn (with 3,492 connections and a total connection strength of 70,524), D. Voyer (with 3,458 connections and a total connection strength of 87,831), D.L. Uttar (with 3,327 connections and a total connection strength of 93,852), D. Lubinski (with 3,257 connections and a total connection strength of 104,342), and J. Wai (with 3,169 connections and a total connection strength of 51,386).

Discussion and Conclusion

Spatial ability encompasses the skill of designing new scenarios by mentally rotating, unfolding, or folding objects (Kuşçu Kılınç, 2022). These skills are crucial in many professions, necessitating individuals to possess

these skills (Turgut & Yenilmez, 2012). Therefore, students must develop and strengthen these critical abilities at a young age. Numerous studies in this field have focused on understanding and enhancing spatial abilities.

Spatial ability has gained significance as a scientific discipline (Lohman, 1993, cited in Ercan, 2018). In this context, a bibliometric analysis of articles related to spatial ability in the Scopus database was conducted. The bibliometric data analysis of studies related to spatial ability in Scopus, spanning from 1939 to the present, is expected to contribute to the field and assist experts in identifying gaps in the literature for future research planning.

In this study, searches were conducted using the keywords "spatial thinking," "spatial visualization," "spatial ability," "spatial thinking skill," and "spatial visualization skill" and their English equivalents: "spatial thinking, spatial ability, spatial visualization, spatial think* skill*, spatial visualization skill*". Studies containing these terms in the title, keywords, or abstract were identified and examined. The search included all past and present studies across all indices, document types, publishers, institutions, authors, languages, and Scopus categories, resulting in a total of 7,345 works.

Analysis of the number of studies by year indicates a noticeable increase in interest in research on this topic since 1974. This increase can be attributed to several factors, including shifts in focus and new reforms in education after the 1970s (Gagne, R. M. (1985) cited in Dokumaci Sütçü, 2020), and advancements in computer technology (Kirsch I. S. (1980) Babu & Ganesan, 2019; Johnson R.B. (1990) cited in Piburn et al., 2005). Although fluctuations have occurred over the years, a general upward trend has been observed. Despite the decline noted in 2024, it should be noted that the research count represented in the graph pertains to the first five months of the year.

When examining the distribution of published works on spatial ability by source, the first position is held by Lecture Notes in Computer Science, including Subseries Lecture Notes in Artificial Intelligence, and Lecture Notes in Bioinformatics. Intelligence, Perceptual and Motor Skills, Personality and Individual Differences, and Learning and Individual Differences follow. The journal Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics has published relevant studies from 1990 to the present. Intelligence has been published since 1978, Perceptual and Motor Skills from 1968 to 2023, Personality and Individual Differences from 1984, and Learning and Individual Differences from 1990 to 2023. A review of these journals reveals that each addresses a different aspect of spatial ability. For example, intelligence serves as a platform for publishing research related to spatial ability because it is a significant component in intelligence measurement and publishes new findings and theories in this area. Perceptual and motor skills deal with both spatial ability and motor skills, with some studies focusing on the

intersection of these areas, as spatial ability involves understanding and processing environmental information, whereas motor skills pertain to physical interaction with the environment. Personality and Individual Differences examines the effects of spatial ability on individual differences. This study explores how spatial ability is related to personality traits and individual variations. Finally, Learning and Individual Differences investigates the relationship between spatial ability, learning processes, and individual differences. This journal focuses on how spatial ability influences learning strategies and success.

Among the researchers with the greatest contributions to the field of spatial ability in the Scopus database from the past to the present, M. Hegarty is the most prolific author. Hegarty is a distinguished researcher who has made significant contributions to spatial ability research. Notably, Hegarty employed various experimental approaches to understand how individuals process and represent spatial information, with a particular focus on cognitive processes involved in spatial visualization. His research has addressed topics such as the role of spatial ability in education, learning strategies, and cognitive mapping. For example, in one of his studies, he investigated individuals' abilities to mentally rotate images of three-dimensional objects, exploring the development and impact of spatial transformation skills (Cognitive Processes in Comprehension of Spatial Language). Hegarty's research has deepened our understanding of how spatial ability can be measured and developed.

The institution with the highest volume of spatial ability research is the University of California. It is followed by Università degli Studi di Padova, Western University, Purdue University, Texas A&M University, the University of Toronto, Pennsylvania State University, the Georgia Institute of Technology, the Chinese Academy of Sciences, and Sapienza Università di Roma. Similarly, the country with the greatest research on spatial ability is the United States. This is followed in order by the United Kingdom, China, Canada, Germany, Italy, Spain, Australia, the Netherlands, and France. This distribution indicates that research on spatial ability is being conducted and continues to be pursued at various locations and institutions around the world.

The majority of publications in the field of spatial ability are in the form of journal articles. This trend may be attributed to the fact that research in this area often involves experimental studies, theoretical analyses, and literature reviews. Spatial ability plays a significant role in cognitive psychology, educational sciences, and applied fields; thus, this variety allows for the exploration of different aspects of spatial ability.

The top research field on spatial ability is the social sciences. Psychology, Computer Science, Medicine, Neuroscience, Engineering, Arts and Humanities, and Mathematics follow. The prominence of the social sciences as the leading field may be attributed to its broad perspective, which encompasses a wide range of interdisciplinary approaches to spatial ability.

An analysis of the top five most-cited works on spatial ability in the Scopus database reveals that all are journal articles. The most-cited article among these top five is "Neurocognitive Deficit in Schizophrenia: A Quantitative Review of the Evidence," published in Neuropsychology in 1998 by Heinrichs et al., and has received 2,375 citations since its publication. This is followed by "Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis," published in Child Development in 1985 by Linn, M.C., and Petersen, A.C., with 2,443 citations; "Magnitude of Sex Differences in Spatial Abilities: A Meta-Analysis and Consideration of Critical Variables," published in Psychological Bulletin in 1995 by Voyer, D., Voyer, S., and Bryden, M.P., with 2,096 citations; "Mental Rotations, a Group Test of Three-Dimensional Spatial Visualization," published in Perceptual and Motor Skills in 1978 by Vandenberg, S.G., and Kuse, A.R., with 1,927 citations; and "Mapping Ecosystem Service Supply, Demand and Budgets," published in Ecological Indicators in 2012 by Burkhard, B., Kroll, F., Nedkov, S., and Müller, F., with 1,602 citations.

An examination of the co-authorship network map for research on spatial ability revealed that 2,029 authors, including M. Hegarty emerged as the most prominent figure among them. M. Hegarty's work and contributions to the field of spatial ability stand out significantly and provide substantial contributions to the literature.

An analysis of the coauthorship network map by country for research on spatial ability lists 91 countries. Among these, the United States is the most prominent. The following countries are in order: the United Kingdom, Germany, Canada, Australia, Switzerland, the Netherlands, France, Italy, and Turkey. This ranking indicates that research on spatial ability is being conducted worldwide.

An analysis of the co-occurrence network map of keywords in research on spatial ability revealed that the term "spatial ability" is the most frequently used. Other commonly used keywords include "spatial thinking," "mental rotation," "spatial visualization," and "cognition." The prominence of these keywords indicates that spatial ability can be divided into multiple subfields, and research is being conducted across these areas.
An analysis of the citation network map by institution for research on spatial ability identified Michigan State University, University of California Santa Barbara, Temple University, and University of Padua as prominent institutions. Similarly, when researchers examine the data by country, the United States stands out. This indicates that significant research on spatial ability is also being conducted at these universities.

An analysis of the co-citation network map for research on spatial ability reveals that the most frequently cited works are "Human Cognitive Abilities: A Survey of Factor Analytic Studies" (1993) by J.B. Carroll, "Statistical Power Analysis for the Behavioral Sciences" (1988) by J. Cohen, and "Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis" (1985) by M.C. Linn and A. C. Petersen. These three studies have been extensively cited. Carroll's work, "Human Cognitive Abilities: A Survey of Factor Analytic Studies"

(1993), investigates human cognitive abilities, employing factor analysis to elucidate the fundamental structures and relationships of cognitive abilities. Cohen's "Statistical Power Analysis for the Behavioral Sciences" (1988) addresses the importance of statistical power analysis in behavioral sciences, explaining how to perform this analysis and the significance of evaluating the power of research findings. Linn and Petersen's "Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis" (1985) explored sex differences in spatial abilities, using meta-analysis to examine the emergence and nature of these differences. These three works have made significant contributions to their respective fields.

An analysis of the co-citation network map for journals in spatial ability research revealed a total of 1,330 journals meeting the criteria, with notable prominence given to Science, PLOS One, Nature, Intelligence, Neuropsychologia, and Cognition. High impact factors, publication of studies across a variety of topics, a rigorous peer review process, and collaborations involving international authors characterize these journals.

An analysis of the co-citation network map of authors in spatial ability research highlights Mary Hegarty as a prominent figure. Hegarty has inspired many researchers in the field of spatial ability through her extensive work in the field. Her in-depth investigations have introduced new perspectives on spatial thinking and visualization, paving the way for significant discoveries in these areas. Hegarty's research has contributed to a broad scientific discussion and advancements in the field of spatial ability.

In conclusion, this study presents a bibliometric analysis of spatial ability research published in the Scopus database from 1939 to the present. A limitation of this study is that it exclusively examined the Scopus database. Researchers may build upon this work by exploring other databases beyond Scopus and conducting more comprehensive bibliometric analyses of spatial ability or related topics. It is anticipated that this research will serve as a valuable data source and provide detailed insights for those interested in the subject.

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