Bibliometric analysis: Spatial skills and gender in education

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ABSTRACT

Spatial skills, the ability to perceive, understand, and manipulate shapes and spatial relationships, are fundamental to human cognition and have a significant impact on success in STEM (Science, Technology, Engineering, and Mathematics) career. The purpose of this study is to analyze the scientific research related to spatial skills and gender in education on Scopus database. This research also reveals the current research trends and research gaps on this subject. Bibliometric analysis is used to answer those objectives, with platforms such as R packages (Bibliometrix) and Vos Viewer software to help the analysis. This study addresses four research issues as follows: (i) the landscape of research on spatial skills and gender; (ii) the leading countries and institutions on spatial skills and gender research; (iii) the most cited journal; and (iv) the most cited authors; (v) the most cited articles; (vi) the most popular and least popular keywords.

http://ejournal.radenintan.ac.id/index.php/desimal/index

INTRODUCTION

According to the National Council of Teachers of Mathematics (NCTM, 2000), one of the standards for geometry in schools is to prompt students to analyse the characteristics of geometric shapes and make mathematical arguments about geometric relationships. Additionally, students should use visualisation, spatial ability, spatial skills, and geometric modelling to solve problems. Spatial ability, a critical cognitive skill, refers to the capacity to understand, reason, and remember the spatial relations among objects or spaces. It encompasses several dimensions, including visualization, manipulation, and reasoning about spatial relationships, which are fundamental for navigating and interacting with the physical world.

Lubinski (2010) highlights spatial ability as a significant yet underutilized predictor of success in STEM (Science, Technology, Engineering, and Mathematics) fields, emphasizing its role in educational and occupational settings where advanced reasoning with figures,

patterns, and shapes is crucial (Lubinski, 2010). Rafi et al. (2005) demonstrate the improvement of spatial ability through the use of a Web-based Virtual Environment (WbVE), showcasing the malleability of spatial skills with appropriate training (Rafi et al., 2005). Further research by Goktepe Yildiz and Ozdemir (2020) on the effects of engineering design-based instruction on middle school students' spatial abilities underscores the educational impact of incorporating spatially demanding activities into the curriculum (Goktepe Yildiz & Ozdemir, 2020). These findings suggest that targeted interventions can significantly enhance an individual's spatial reasoning capabilities, offering a pathway to improving educational outcomes and broadening participation in STEM disciplines.

The Indonesia Ministry of Education, in previous curriculum (called *Kurikulum 13*) and current curriculum (called *Kurikulum Merdeka*), explained that geometry is one of the important field studies in mathematics that Indonesian student to be mastered along with algebra, numbers, calculus, data analysis and probability. In current curriculum (called *Kurikulum Merdeka*), the learning objective that related to geometry in primary level (grade 1 to 6) are identify 2D or 3D shapes, determine the position of an object relative to other object or in maps, construct and deconstruct 2D or 3D shapes, develop visual spatial in 3D object. Meanwhile, the learning objective that related to geometry in junior high level (grade 7 to 9) are construct nets for 3D shapes, identify relationship between two lines, explain relationship between congruency and symmetry among geometric figures, and proof the Pythagorean theorem. On the other hand, the learning objective that related to geometry in senior high level (grade 10 to 12) are solve problems involving trigonometric formula, and solve problem involving arc length, circumference, and area of circles (Badan Standar, Kurikulum, dan Asesmen Pendidikan, 2022).

Spatial skills, the ability to perceive, understand, and manipulate shapes and spatial relationships, are fundamental to human cognition and have a significant impact on success in STEM (Science, Technology, Engineering, and Mathematics) fields (Khine, 2017; Tian et al., 2023; Wai et al., 2009). Other study shows that spatial and mathematics abilities connection not unique, spatial skill also has a significant impact in PISA reading literacy, English/Language Arts (ELA) achievement even gamers performance in tournament (Adams & Mayer, 2012; Mutavdžin, 2020; Rutherford et al., 2018). Evidence suggests that these skills extend their influence to reading literacy and English/Language Arts (ELA) achievement, where the capacity to construct mental images from text enhances comprehension and interpretation. In the realm of digital gaming, spatial abilities have been linked to gamers' performance, indicating their importance in navigating and succeeding in virtual environments.

Despite their importance, research indicates a persistent gender gap, with males consistently outperforming females on tasks requiring spatial reasoning, mental rotation, and spatial visualization (Johnson et al., 2022; Lee et al., 2019; Ruggiero et al., 2008). This disparity raises concerns about equity in educational opportunities and outcomes, it implies women's underrepresentation in STEM majors and careers (Tian et al., 2023). The gender gap in spatial abilities raises concerns about the fairness of educational practices and the potential for unconscious biases that may discourage females from pursuing STEM-related fields. The persistent difference in performance underscores the need for targeted interventions and educational strategies aimed at mitigating this gap,

emphasizing the importance of creating an inclusive environment that supports the development of spatial skills among all students.

Several studies have explored the relationship between spatial skills and gender in education. However, there needs to be more systematic reviews that identify research trends in this area. The bibliometric analysis was conducted to examine the literature on spatial skills and gender in education. Bibliometric analysis offers a systematic method to review and quantify the volume of research conducted on spatial skills and gender within educational contexts. By examining yearly research output, country distribution, publication institutions, authors, publication citations, and thematic trends, this approach provides insights into the evolution of the field, key contributors, and potential gaps in the literature (Palupi et al., 2023; Pertiwi et al., 2023; Teapon et al., 2023). Through this analysis, we seek to contribute to the ongoing dialogue on spatial skills and gender in education, offering evidence-based recommendations to educators, policymakers, and researchers. By understanding the landscape of existing research, we can better address the research gap in spatial skills and gender in educational context.

This research aims to guide future research in this field. Research questions were established to keep the analysis focused on: (1) How is the landscape of research on spatial skills and gender? (2) What are the leading countries and top institutions that are most productive in spatial skills and gender research? (3) Which journal is the most cited on spatial skills and gender research? (4) Which are the most cited authors on spatial skills and gender research? (5) What are the most cited articles on spatial skills and gender research? Furthermore, (6) What were the most popular and least popular keywords that researchers selected on spatial skills and gender?

METHOD

To carry out the search, researcher utilized the query string and filter using Scopus advanced search. The query string used TITLE-ABS-KEY (("spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills" OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR "spatial intelligence" OR "mental rotation") AND ("gender")) AND PUBYEAR > 1976 AND PUBYEAR < 2024 AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (PUBSTAGE , "final")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (EXCLUDE (SUBJAREA , "NEUR") OR EXCLUDE (SUBJAREA , "MEDI") OR EXCLUDE (SUBJAREA , "BIOC") OR EXCLUDE (SUBJAREA , "PHAR") OR EXCLUDE (SUBJAREA , "HEAL") OR EXCLUDE (SUBJAREA , "IMMU") OR EXCLUDE (SUBJAREA , "NURS")).

The search keyword was chosen after considering earlier research (Harris, 2021; Hidayat et al., 2023; Lee et al., 2019). Query string TITLE-ABS-KEY defines the title, abstract, or keywords to assist the search engine in finding articles that are pertinent to the main subject. This research focuses on spatial skills and gender in educational settings so that the filter is applied to limit the result. The process is visualized in Figure 1. The PUBYEAR query makes sure the publication is published in a certain period, in this case, between 1976 and 2023. Meanwhile, query string (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (DOCTYPE , "ar")) helps the search engine capture only articles from journals (exclude conference proceeding, book series, and book). The query (LIMIT-TO(PUBSTAGE, "final")) helps the search engine to only capture publications that

have already been published; this filter excludes the articles in the press and articles that are still in the review process. The query EXCLUDE (SUBJAREA, "...") means the search engine excludes the specific subject area; in this research, we focus on the education field and exclude the research conducted in medical fields such as Neuroscience, Medicine, Biochemistry, Genetics and Molecular Biology, Pharmacology, Health Professions, Toxicology and Pharmaceutics, Immunology and Microbiology, and Nursing.
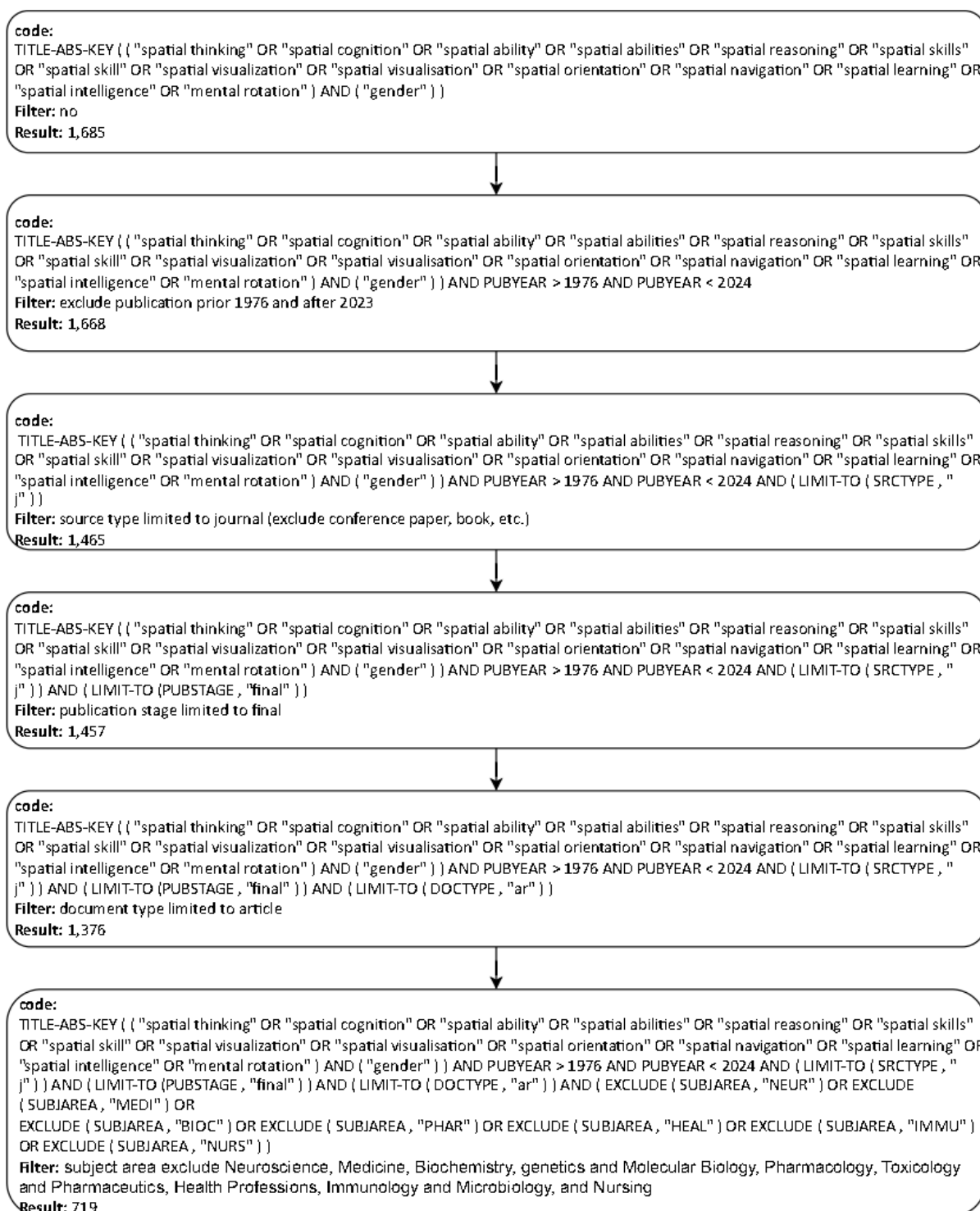
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code:
TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) )
Filter: no
Result: 1,685
```

```
code:
TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) ) AND PUBYEAR > 1976 AND PUBYEAR < 2024
Filter: exclude publication prior 1976 and after 2023
Result: 1,668
```

```
code:
 TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) ) AND PUBYEAR > 1976 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SRCTYPE , "
j" ) )
Filter: source type limited to journal (exclude conference paper, book, etc.)
Result: 1,465
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code:
TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) ) AND PUBYEAR > 1976 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SRCTYPE , "
j" ) ) AND ( LIMIT-TO (PUBSTAGE , "final" ) )
Filter: publication stage limited to final
Result: 1,457
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code:
TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) ) AND PUBYEAR > 1976 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SRCTYPE , "
j" ) ) AND ( LIMIT-TO (PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) )
Filter: document type limited to article
Result: 1,376
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code:
TITLE-ABS-KEY ( ( "spatial thinking" OR "spatial cognition" OR "spatial ability" OR "spatial abilities" OR "spatial reasoning" OR "spatial skills"
OR "spatial skill" OR "spatial visualization" OR "spatial visualisation" OR "spatial orientation" OR "spatial navigation" OR "spatial learning" OR
"spatial intelligence" OR "mental rotation" ) AND ( "gender" ) ) AND PUBYEAR > 1976 AND PUBYEAR < 2024 AND ( LIMIT-TO ( SRCTYPE , "
j" ) ) AND ( LIMIT-TO (PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE , "ar" ) ) AND ( EXCLUDE ( SUBJAREA , "NEUR" ) OR EXCLUDE
( SUBJAREA , "MEDI" ) OR
EXCLUDE ( SUBJAREA , "BIOC" ) OR EXCLUDE ( SUBJAREA , "PHAR" ) OR EXCLUDE ( SUBJAREA , "HEAL" ) OR EXCLUDE ( SUBJAREA , "IMMU" )
OR EXCLUDE ( SUBJAREA , "NURS" ) )
Filter: subject area exclude Neuroscience, Medicine, Biochemistry, genetics and Molecular Biology, Pharmacology, Toxicology
and Pharmaceutics, Health Professions, Immunology and Microbiology, and Nursing
Result: 719
```

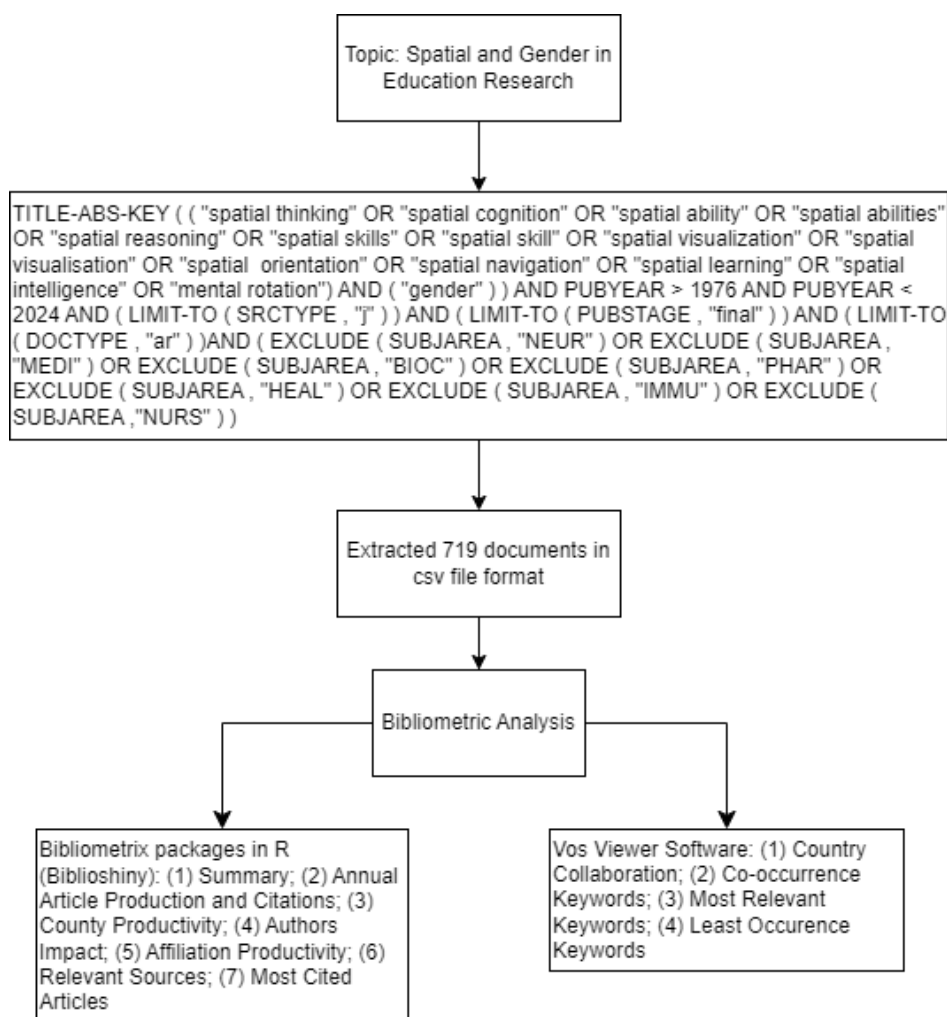**Figure 1.** Query Search and Filter in Scopus

Figure 2. Research Process

This research aimed to provide a comprehensive overview of the literature on spatial skills and gender in education research found in Scopus. By using analytical tools such as Bibliometrix and VOS Viewer, we were able to identify patterns and trends in the literature. These tools examine networks of authors, journals, universities, and nations, as well as keywords based on citations and frequency analysis techniques. We also identified the most commonly used keywords associated with spatial skills and gender in education research. The Bibliometrix packages produce tables, such as the data summary table, country table, affiliation table, source table, and article tables. Additionally, the packages generate descriptive figures such as the annual number of articles and cumulative articles figure, and the annual number of articles and average citation per article annually figure. The VOS viewer software produces a country cluster related to international cooperation in research and a keyword cluster related to co-occurring keywords in research Figure 2.

RESULTS AND DISCUSSION

Table 1 presents a summarized bibliometric analysis of literature in the field of spatial skills and gender research, covering a period from 1981 to 2023. A comprehensive review of 308 journals has resulted in the accumulation of 719 documents pertinent to the subject. This body of research has demonstrated steady growth, with an annual increase of 9.24%. Reflecting the academic impact of these documents, the average citation rate per document stands at 34.90, suggesting a

robust engagement within the scholarly community.

A total of 1,760 authors have contributed to this field, indicating a dynamic and extensive collaborative network. However, a relatively small fraction of these, 96 authors, have produced documents independently. When examining the collaborative nature of the research, it is noted that single-author documents account for 112 of the totals, while approximately 3.10 co-authors produce the average document. This suggests a moderate level of collaboration, which is further underscored by the 14.74% of these collaborations being international.

The data highlights the significant collaborative efforts and the global nature of research within the realms of spatial skills and gender studies, as revealed by the bibliometric tools utilized for this analysis. This reflects not only the growing interest and scholarly activity in this area but also the cross-border academic partnerships that enrich the research landscape.

Table 1. Data Summary

Content	Result
General Information	
Period	1981 - 2023
Number of Source (Journal)	308
Number of Documents	719
Annual growth rate	9.24%
Number of citations per document (average)	34.90
Author	
Authors	1,760
Authors of single-author document	96
Author's collaboration	
Documents of single author	112
Co-Authors per Document	3.10
International co-Authorships (%)	14.74

Figure 3 presents the publication trends in spatial skills and gender research from 1981 to 2023. It features a bar chart with annual publication counts and an overlaid cumulative line graph. Initially, the field shows a modest output, with a gradual increase in publications. However, a pronounced surge in productivity became evident in the early 2000s, reflected by the steepening curve of the cumulative line. This uptick indicates a burgeoning interest in spatial skills and gender issues within the scholarly community. By 2023, the total number of articles reach 719, highlighting a robust and growing body of research. The recent years on the graph are marked by the highest annual publication rates, suggesting a significant expansion in the field, possibly driven by evolving societal interests, academic discourse, and

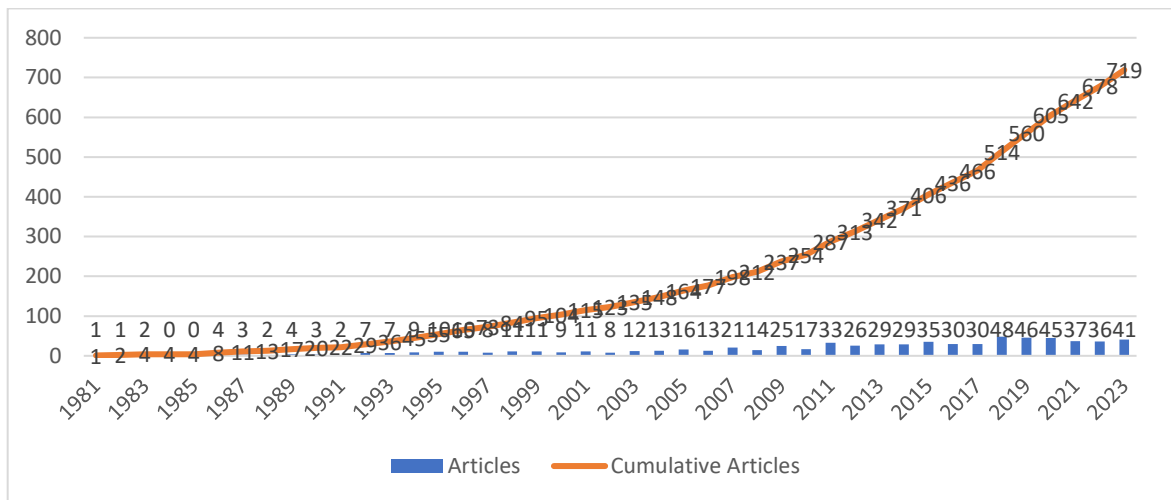interdisciplinary approaches to spatial skills and gender studies.

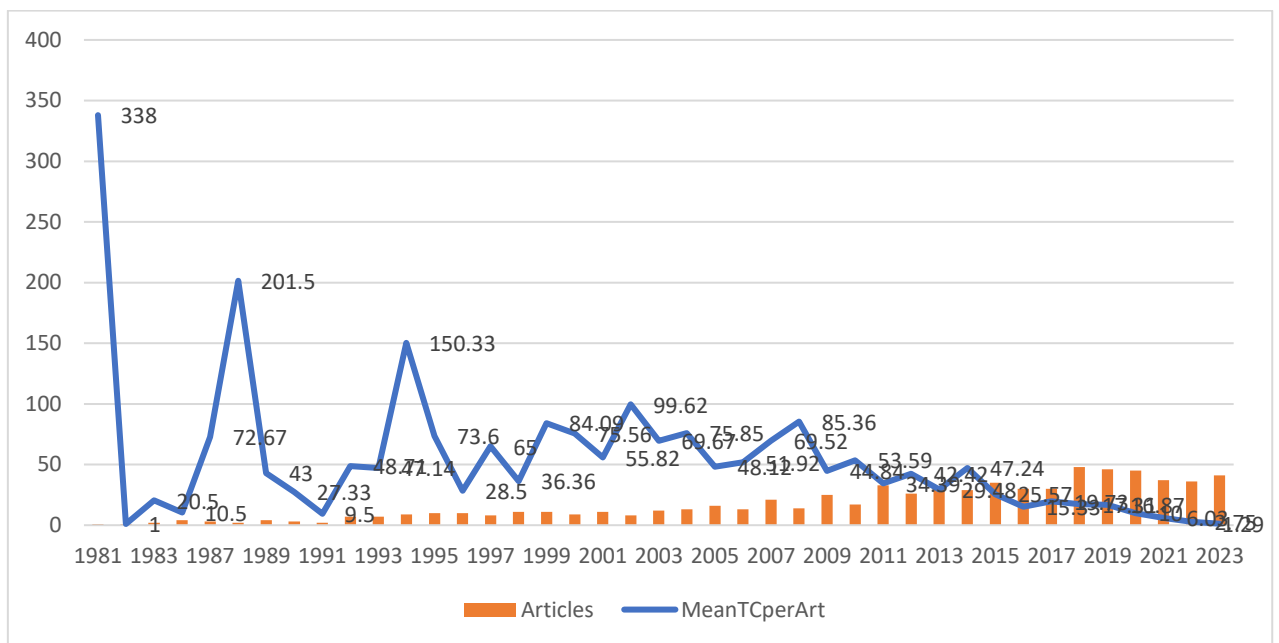**Figure 3.** Annual number of articles and cumulative articles

Figure 4. Annual number of articles and Average Citation per Article Annually

Figure 4 illustrates the trajectory of spatial skills and gender research from 1981 to 2023, with a bar chart indicating the number of articles published annually and a line graph showing the mean citations per article each year. The publication pattern is not uniform, with specific years, notably 1991, 2001, and 2011, showing a significant peak in citations per article, suggesting those years saw articles of considerable influence. Although the number of publications generally grows over time, the citation impact per article varies, with notable spikes in specific years. The recent decline in mean citations per article against the steady or increasing publication rate may imply that while the field continues to expand with new research, these contributions have yet to achieve the same level of citation impact as those in the past or that the field has become more saturated, making it harder for new publications to gain prominence.

This analysis encapsulates not just the quantitative growth of the literature but also the qualitative reception and influence of the research within the academic community.

Table 2 outlines the top five countries contributing to spatial skills and gender research, ranked by the number of articles produced. The United State leads substantially with 685 articles, followed by Germany with 202, the Italy with 170, United Kingdom with 132, and Canada with 109. The total citations column indicates the extent to which research from these countries has been referenced, with the United States again leading with 7,072 citations. However, when looking at citations per article, the landscape shifts. Canada's research has a higher impact on average, with 16.70 citations per article, which is significantly higher than that of the other countries listed. United State follows with an average of 10.32 citations per article, closely paralleled by the Italy with 9.71. the United Kingdom and Germany have lower citations per article, with 7.89 and 6.96, respectively. This data suggests that while the United States produces the most research in quantity, Canadian research in this field has the highest average impact per article. The table highlights the varying scales and impacts of research contributions by different countries in spatial skills and gender studies.

Figure 5 is a network map visualizing international cooperation in spatial skills and gender research. In such a map, nodes represent countries, and the connecting lines indicate collaborative relationships between these countries. The size of each node often correlates to the volume of research output or the number of collaborations that the country has in the field. The thickness of the connecting lines represents the strength or frequency of collaborations, and the color coding could differentiate the regions or the intensity of collaboration. For example, the strong line between the United States and the United Kingdom suggests a high level of collaborative research between these two countries. The map provides a visual representation of how countries are interconnected in the realm of spatial skills and gender research, highlighting the global nature of academic research and the importance of international partnerships in advancing knowledge in this field. On the other hand, this map can be a powerful tool for understanding the dynamics of research collaboration and for identifying key contributors and potential opportunities for new partnerships.

Table 2. List of Countries with The Most Article

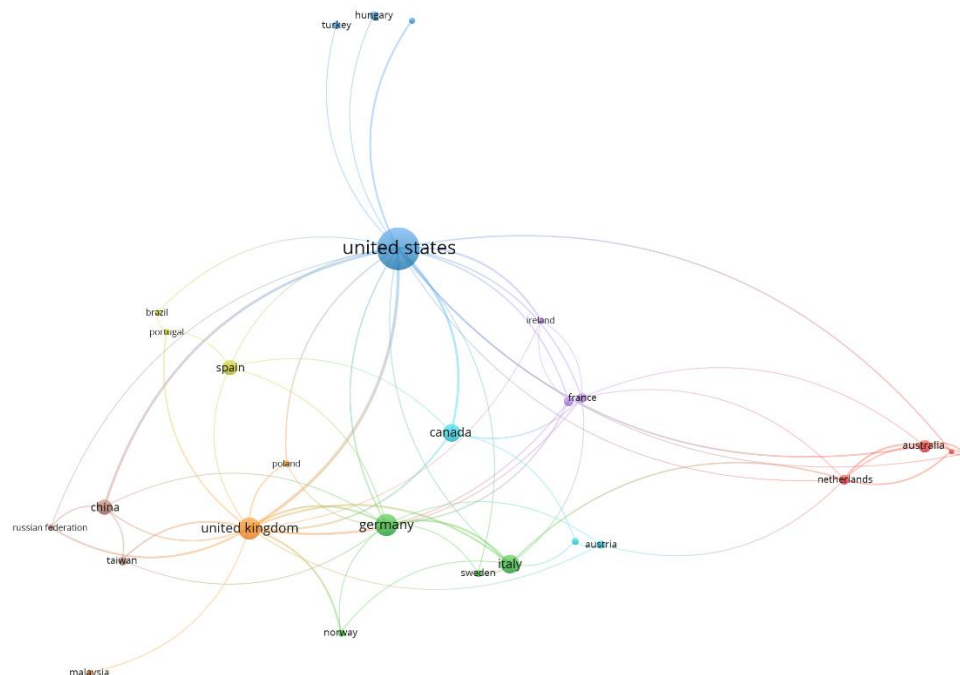| No.	Country	Total articles	Total citations	Total citations/ Total articles
1	United State	685	7,072	10.32
2	Canada	109	1,820	16.70
3	Italy	170	1,651	9.71
4	Germany	202	1,406	6.96
5	United Kingdom	132	1,042	7.89

Figure 5. Illustration of International Cooperation

At the global level, the United States stands out with numerous connections, indicating its central role in international research collaboration followed by United Kingdom and Germany. Meanwhile, Hungary, Türkiye, South Korea and Malaysia appear as an isolated node with a single thin line, indicating minimal collaborative interactions in this specific research area compared to other countries. Asian countries, identified by their geographical position in the network, also show significant collaborative ties, China and Taiwan being particularly notable. These connections signify joint publications, shared research projects, or other forms of academic partnership. Focusing on Southeast Asia, Malaysia is the only country engaged in collaboration with other countries. The links between Malaysia and its neighboring countries would represent regional cooperation, which is essential for addressing local issues within spatial skills and gender research.

Table 3 lists the academic affiliations that have contributed to the production of spatial skills and gender research, detailing the volume of articles produced by each institution. University of Koblenz-Landau in Germany and University College London in the United Kingdom produce 36 and 33 articles, respectively, indicating a robust research output in this field. Close behind are institutions from Italy and the United States, University of Padova and Boston College producing 33 and 31 articles. The University of Regensburg in Germany also shows significant scholarly activity with 29 articles. The table further illustrates a diverse international contribution to the field, with universities from the China, United States, and Canda being represented. Notably, Beijing Normal University, University of California, Université De Montréal, University of New Brunswick, and University of Georgia each

display substantial involvement with 23,19,17 and 16 articles, respectively. This data underscores the global nature of spatial skills and gender research, with multiple countries and their academic institutions actively engaged in advancing the discourse. The spread of articles across these institutions reflects not only the international interest in spatial skills and gender studies but also the varied academic environments in which this research is being fostered.

Table 3. Articles Production Based on Affiliation

Affiliation	Country	Articles
University of Koblenz-Landau	Germany	36
University College London	United Kingdom	34
University of Padova	Italy	33
Boston College	United States	31
University of Regensburg	Germany	29
Beijing Normal University	China	23
University of California	United States	23
Université De Montréal	Canada	19
University of New Brunswick	Canada	17
University of Georgia	United States	16

Table 4. Articles production based on Source

Sources	Scimago Rank	Total Articles	Total Citation
Sex Roles	Q1	22	1975
Learning And Individual Differences	Q1	38	1511
Developmental Psychology	Q1	12	1395
Psychological Science	Q1	6	1317
Personality And Individual Differences	Q1	19	1095
Journal of Environmental Psychology	Q1	10	770
American Psychologist	Q1	2	694
International Journal of Science Education	Q1	6	670
Archives of Sexual Behavior	Q1	14	624
Journal of Applied Developmental Psychology	Q1	4	608

Table 4 showcases the top ten journals ranked by total citations, which have published articles on spatial skills and gender research. All journals listed are in the first quartile (Q1) according to Scimago Journal Rank (SJR), indicating they are highly regarded in their respective fields. "Sex Roles" leads with the highest number of citations (1,975) for 22 articles, suggesting that the research published in this journal has a significant impact on the field. "Learning and Individual Differences" follows with 38 articles produce 1,511 citations, and "Developmental Psychology" has 12 articles cited 1,395 times, indicating that although they have fewer articles, their research is highly influential.

"Psychological Science" with six articles, accumulating 1,317 citations, which implies it is a major source for research in this domain. "Personality And Individual Differences" and "Journal of Environmental Psychology" also show

substantial contributions, with 1,095 and 770 citations for 19 and 10 articles, respectively. "American Psychologist" has only two articles but relatively high citation count of 694, indicating those articles are seminal in this field. The "International Journal of Science Education," "Archives of Sexual Behavior," and "Journal of Applied Developmental Psychology," round out the list, each with a significant number of citations, showcasing their role in disseminating influential research in spatial skills and gender studies. These citation figures reflect the journals' prestige and the importance of their contributions to the discourse on spatial skills and gender issues. High citation counts typically indicate that the published research has been widely recognized and utilized by the academic community.

Table 5. Top 10 Total Citation Based on Authors'

Author	Scopus ID	Current Affiliation	Country	Current h-index	Total Citation
Feng, Jing	55468551300	University of Toronto	Canada	14	1,222
Spence, Ian	36094761800	University of Toronto	Canada	5	1,220
Lawton, Carol A.	7005828159	Purdue University Fort Wayne	United States	9	829
Pratt, Jay	7203084492	University of Toronto	Canada	44	792
Feingold, Alan J	35372759200	Oregon Social Learning Center	United States	37	681
Pezaris, Elizabeth E.	6505834220	Boston College, Chestnut Hill	United States	11	625
Sorby, Sheryl A	7003314490	University of Cincinnati	United States	20	606
Huttenlocher, J	7003402247	The University of Chicago	United States	58	584
Levine, Susan C	7403575948	The University of Chicago	United States	57	584
Casey, Beth M	7201892340	Boston College, Chestnut Hill	United States	24	566

Table 6 lists the ten most-cited articles in the domain of spatial skills and gender research, indicating the impact and recognition these studies have within the academic community. The leading article, "Playing an Action Video Game Reduces Gender Differences in Spatial Cognition," by Feng et al. (2007), published in "Psychological Science," has accumulated 792 citations, suggesting its findings have made a substantial impact on the field. The second most-cited article, "Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety," by Lawton (1994), published in "Sex Roles," has been cited 571 times, indicating its continued relevance in discussions on spatial cognition and gender.

Table 6. Ten most-cited articles

Title	Journal	Scimago Rank	Year	Total Citations
Playing an Action Video Game Reduces Gender Differences in Spatial Cognition (Feng et al., 2007)	Psychological Science	Q1	2007	792
Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety (Lawton, 1994)	Sex Roles	Q1	1994	571
Educational Research in Developing 3-D Spatial Skills for Engineering Students (Sorby, 2009)	International Journal of Science Education	Q1	2009	418
Gender differences in spatial orientation: A review (Coluccia & Louse, 2004)	Journal of Environmental Psychology	Q1	2004	379
Cognitive gender differences are disappearing (Feingold, 1988)	American Psychologist	Q1	1988	355
Early sex differences in spatial skill (Levine et al., 1999)	Developmental psychology	Q1	1999	350
Video Games and Spatial Cognition (Spence & Feng, 2010)	Review of General Psychology	Q1	2010	349
How large are cognitive gender differences? A meta-analysis using !w² and d.. (Hyde, 1981)	American Psychologist	Q1	1981	337
Effect of video game practice on spatial skills in girls and boys (Subrahmanyam & Greenfield, 1994)	Journal of Applied Developmental Psychology	Q1	1994	293
Effects of video game playing on measures of spatial performance: Gender effects in late adolescence (Okagaki & Frensch, 1994)	Journal of Applied Developmental Psychology	Q1	1994	267

The presence of multiple articles from high-ranking Q1 journals, such as "Developmental Psychology," "American Psychologist," and "Journal of Applied Developmental Psychology," reflects the quality and high regard of research published in these sources. These articles, spanning from 1981 to 2010, cover a range of topics, from the effects of video games on spatial skills to educational research in developing spatial skills for engineering students, demonstrating the diversity and evolution of the field over the years.

Citations for these articles range from 267 to 792, illustrating the significant and sustained influence these studies have had on subsequent research. The concentration of articles from the 1990s and 2000s indicates a period of active and influential research in spatial skills and gender studies, with enduring impact leading to a high citation count over time. The table not only underscores the seminal contributions of these articles but also reflects the broad interest in understanding gender differences in spatial cognition and the factors influencing these differences.

Figure 6. Co-occurrence Keyword

Figure 6 is a visualization of keyword co-occurrence within spatial skills and gender research, which maps the relationships between various terms used in this field. In such a network, each node represents a keyword, and the lines between them indicate that these terms are frequently mentioned together in the literature. Central to this network are the terms "gender difference," "spatial ability," "mental rotation," "gender," and "sex differences," which are larger and more centrally located, suggesting that they are key concepts within this research domain. These terms serve as hubs, with many connections to other keywords, implying their widespread relevance in studies and discussions surrounding spatial skills and gender research. Keywords related to cognitive and educational aspects, such as "spatial reasoning," "spatial perception," and "academic achievement," are also present and interconnected, indicating a strong focus on how gender differences may influence or correlate with spatial skills in educational contexts. The presence of "video games," "virtual reality," and "augmented reality" suggests research interest in how digital environments may relate to spatial abilities and gender.

Moreover, there are terms like "stereotypes," "gender roles," and "stereotype threat," which point to the social and psychological dimensions being explored in relation to spatial abilities and gender differences. This indicates an investigation into how societal expectations and psychological factors might influence or be influenced by gendered perceptions and abilities in spatial contexts. The network's complexity and the numerous connections between keywords highlight the

multidisciplinary nature of spatial skills and gender research, encompassing cognitive psychology, educational theory, technology, social psychology, and developmental studies. The visualization serves as a conceptual map, guiding researchers to understand how various themes and concepts in spatial skills and gender research are interrelated.

Table 7. Top 10 co-occurrence keywords

Keyword	Occurrences	Total link strength
mental rotation	94	200
gender differences	115	195
gender	82	144
spatial ability	75	142
sex differences	34	69
spatial skills	29	57
spatial cognition	30	55
stem	19	50
spatial visualization	28	49
stereotype threat	18	48

Table 7 reflects current research trends in spatial skills and gender studies by highlighting the most frequently co-occurring keywords and their associated link strengths, which indicate the degree of association between these terms in the literature. "Mental rotation" and "gender differences" leads with the highest occurrences and link strength, suggesting that the exploration of disparities between genders in spatial abilities is a prominent and well-connected theme within current research. This mirrors the broader societal focus on gender equality, especially in educational contexts.

The term "gender" itself, apart from "gender difference," also has a high occurrence and link strength, indicating that gender is being studied not just in terms of difference but also as a central factor within a range of contexts in spatial ability research. The significant presence of "spatial ability" indicates a specific interest in the cognitive processes underlying spatial reasoning, with particular attention to how these abilities may vary by gender. This aligns with the effort to understand the root causes of gender disparities in STEM fields, where spatial abilities are often critical. The keywords "stem" underscores the intersection of gender research with educational outcomes in these fields, reflecting the trend toward encouraging diversity and addressing gender imbalances in STEM education. "Spatial skill," "spatial cognition," and "spatial visualization" are closely associated with research into educational strategies and cognitive development, possibly driving the development of new teaching methods and learning tools that are sensitive to gender differences in spatial processing.

The inclusion of " stereotype threat " with a lower occurrence but notable link strength may point to a niche but important aspect of spatial abilities research, possibly in relation to navigation skills, which could have implications for a variety of practical applications, from

technology design to educational practice. In summary, the table highlights the central themes and the interconnected nature of gender and spatial ability research, which is reflective of the current scholarly focus on understanding and addressing gender-based differences in cognitive abilities and their implications in education and beyond.

Table 8. Least 10 co-occurrence keywords

Keyword	Occurrences	Total link strength
homosexuality	3	3
instructional animations	3	3
media in education	3	3
spatial visualization ability	3	3
cognitive abilities	3	1
perception	3	1
sexuality	3	1
spatial intelligence	4	1
eye tracking	3	0
factor analysis	3	0

Table 8 lists the ten keywords with the least co-occurrence and link strength in spatial skills and gender research, suggesting these topics may be less explored or emerging areas within the field. "Homosexuality," "instructional animations," "media in education," and "spatial visualization ability" each occur three times and have a link strength of three, indicating that while they are recognized within the literature, their connection to spatial skills and gender research is not as well established. This could imply potential for further exploration of how various educational mediums intersect with gender and spatial understanding.

Term "cognitive abilities" and "perception," are listed with occurrences of three and link strengths of three and one, respectively, signaling that their roles in the education and development of spatial skills in the context of gender are topics that might benefit from additional research. Term "sexuality" has three occurrences and a link strength of one, which could indicate an emerging interest in the broader implications of sexual orientation in spatial ability and gender studies.

Term "spatial intelligence" appears slightly more with four occurrences but still has a low link strength of one, hinting at a topic that is recognized but possibly not fully explored in connection with gender differences. Term "eye tracking" and "factor analysis" stands out with three occurrences but no link strength, suggesting it is an uncharted methodological approach within this field. Its inclusion could point to a new avenue for research, exploring how eye movement patterns relate to spatial cognition and whether there are gender-related differences in this area. Overall, these keywords point to potential gaps or emerging trends in spatial skills and gender research, offering opportunities for new studies to expand the field's

boundaries and explore these less-charted connections.

CONCLUSIONS AND SUGGESTIONS

This study presents a bibliometric analysis of related spatial skills and gender to understand the areas in which researchers are studying these issues, the trend in the number of articles published from year to year, the main countries or territories where the documents were published, the documents classified by affiliation in the period analyzed, the leading journals in which the papers were published, the top ten authors with the most publications, as well as the most cited articles. This study shows that spatial skills and gender research in education that gets much use in some time spans 1981-2023 obtained 719 articles from 308 journals. The trend of publications related to spatial skills and gender in education has increased since the 2000s. The United States is the most influential country in publications related to this field, with 685 publications with 7,072 citations, and the university with the highest number of documents published during the analyzed period is the University of Koblenz-Landau (Germany), with 36 publications. The most cited journal on this issue Sex Roles, with 1,975 citations from 22 articles produced. Finally, the most cited article was titled "Playing an Action Video Game Reduces Gender Differences in Spatial Cognition" (Feng et al., 2007), with 792 citations. According to the results of keyword co-occurrence, "mental rotation," "gender difference," "gender," and "spatial ability" were among the most frequently used keywords. These findings of the study could help researchers decipher the most frequently addressed themes in the field and provide directions and references for future research.

On the other hand, "homosexuality," "instructional animations," and "media in education" were among the least used keywords in this field. These findings could help researchers discover the least theme researched by scholars or find the research gap in this field. On the other hand, this research has several limitations, namely: (1) the data analyzed only comes from the Scopus database, so the researchers suggest that future research could explore other databases such as Google Scholar, Web of Science, ResearchGate, JSTOR, and others so that the data collected becomes more comprehensive; (2) we performed a quantitative analysis, future studies should focus on a qualitative analysis, such as content analysis or content discourse analysis.

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