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Mapping the landscape of spatial literacy research: Bibliometric analysis

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ABSTRACT

The study aims to provide a comprehensive overview of spatial literacy research through a bibliometric analysis, focusing on its development, essential themes, key contributors, and collaboration patterns. Using statistical text-mining and citation link-based clustering techniques, 690 spatial literacy publications from the Scopus database were analyzed, with data extracted on February 18, 2024. The analysis revealed a steady increase in spatial literacy publications, peaking in 2009, and identified key peaks in cited papers in 1996, 2003 and 2012, with a subsequent decline post-2012. Document profiles primarily consisted of articles (60.14%) and sourced from journals (67.97%), with The Journal of Geography being the most active title. Notably, Newcombe, N.S., emerged as the most productive author, while the work of Bednarz and Kemp received the highest number of citations. 'The Separability of Working Memory Resources for Spatial Thinking and Language Processing: An Individual Differences Approach' by Shah and Miyake was identified as the most influential document, garnered a minimum of 100 citations per written document. Additionally, the United States stood out with both the largest number of publications and the highest citation impact in spatial literacy research. This bibliometric analysis provides valuable insight into the spatial literacy research landscape, guiding for future research directions and fostering collaborations in this field.

Contribution/ Originality: The originality of this study lies in its integration of advanced bibliometric tools such as Scopus, Harzing's Publish or Perish software, and VOSviewer. This fusion facilitates thorough data extraction, visualization, and impact analysis in the field of spatial literacy, thus advancing bibliometrics within spatial cognition studies.

1. INTRODUCTION

COVID-19 pandemic has heightened the importance of spatial literacy by demonstrating the necessity of spatial skills in interpreting geographic information. This includes tasks like planning routes that minimize exposure, and adapting to changes in spatial dynamics prompted by restrictions. According to Solem, Huynh, and Boehm (2015) defining and measuring spatial thinking remains a notably challenging task despite fifty years of research on spatial cognition. The literature on spatial thinking is dispersed across various fields, such as geography education, cognitive psychology, learning sciences, and neurosciences, each emphasizing different facets of spatial cognition. Recognizing spatial cognition as a crucial component in their respective work, researchers and scholars from various disciplines have contributed to its study. This diverse group includes neuroscientists,

ethnologists, psychologists, computer scientists, geographers, mathematicians, sociologists, architects, linguists, anthropologists, and philosophers (Hegarty, 2011; Lee & Jo, 2022; Newcombe & Frick, 2010). A bibliometric treatment would indeed be necessary to help navigate among the many literatures on spatial cognition, delving into how we perceive space and develop spatial thinking. Spatial literacy involves visualizing, interpreting, and reasoning using location, distance, direction, relationships, movement, and change in space, making it a multifaceted and crucial area of study. This bibliographic scrutiny brings together the different perspectives form various areas of study and contribute to a more thorough exploration of how spatial thinking works. To map out the landscape of spatial literacy research, this bibliometric analysis aims to address the following research questions (RQ);

RQ1: How is the development and distribution of research on spatial literacy over time?

RQ2: What are the essential themes and topics that have emerged in spatial literacy research?

RQ3: Who are the key contributors and collaborators in the field of spatial literacy research?

2. LITERATURE REVIEW

2.1. Bibliometric Analysis

Bibliometrics is a statistical analysis method of scientific publications, incorporating, both the definitive qualities, such as the number of articles published by year, and the evaluative quality, like citation counts (Emet, Akbas, Kocak, Cander, & Aslan, 2016; McBurney & Novak, 2002). This method involves measuring various aspects of publications. These aspects include content such as publications by year, author, author's affiliation, major keywords, source title and language, and publication impact through citation counts by authors (Ellegaard & Wallin, 2015). Before eligible records can undergo bibliometric analysis, bibliographic data must be sourced. In this study, Scopus, one of the world's largest multidisciplinary bibliographic databases was employed to provide a comprehensive understanding of spatial literacy research (Donthu, Kumar, Mukherjee, Pandey, & Lim, 2021; López-Muñoz et al., 2018). Scopus, renowned for its vast abstract and citation database of peer-reviewed literature, encompasses journal articles, conference proceedings, and book chapters. With a wider and more inclusive content coverage, including individual author profiles, affiliates, serial sources, and interrelated interface from its bibliographic database, Scopus proves to be an invaluable source for bibliometric analysis (Pranckutė, 2021)

2.2. Past Studies

Spatial literacy is a subject extensively studied by experts in human development, education, psychology, language, communication, and culture. Despite its significance, there is a scarcity of research analysing its publication content and impact. A Google Scholar search for "spatial literacy" yielded 2,940 results, but only two bibliometric studies by de Queiroz (2021b) were identified. His article titled *Spatial Analysis: A Bibliometric Approach (1950–2019)* and *Spatial Thinking: A Bibliometric Analysis (1970–2019)* offer an intriguing insights into the evolution and growth of research in the field of spatial analysis and spatial thinking. In the 70-year period covered in his first analysis, the annual growth rate of publication on spatial literacy was 11.5%, experiencing rapid growth between 1990 and 2019, with the number of publications growing 128 times (17.55%). Ecology or environment emerged as the most representative journal and cited subject in spatial literacy research. Geography demonstrated a strong co-citation strength, and the most productive disciplines included environmental sciences, public environmental and occupational health, and multidisciplinary geosciences especially of Geographic Information Systems (GIS) (de Queiroz, 2021a).

Queiroz's second paper examined 474 manuscripts on spatial thinking published between 1970 and 2019 in the Web of Science Core Collection. Notably, there has been a surge in publication since 2008, especially in 2011, 2013, and 2017. The most frequently used keywords were 'knowledge', 'ability', 'education', and 'geographic information systems' (GIS). Hegarty was the most productive author, with more than 50 citations and the most notable publication was the Journal of Geography, the Journal of Geography in Higher Education, and the

International Conference: Spatial Thinking and Geographic Information Sciences (Tokyo) (de Queiroz, 2021b). Both studies collectively showcase the significant growth and evolution in spatial thinking research, with bibliometric analyses providing a more detailed understanding of trends and patterns, thus highlighting the importance of interdisciplinary research in driving this growth within spatial literacy studies

3. METHOD

3.1. Search Strategy

After defining the aim and scope of this bibliometric study, publications on spatial literacy were mined by utilizing the extensive Scopus database. A search was conducted on February 18, 2024, and limited to TITLE (spatial* AND education OR literacy OR thinking) yielded 1046 publications. The search was refined using specific titles for greater accuracy, as the title of a research article provides a concise summary of its main focus and content. From this, 356 documents were excluded from the bibliometric analysis, as they were not directly related to spatial literacy. Excluded publications focused on socio-economic disparities, socio-territorial conflicts, regional and political issues on urban planning, or landscaping, and other unrelated research. The remaining 690 publications were accepted for a more comprehensive bibliometric analysis. According to Donthu et al. (2021) a dataset with more than 500 papers is considered large enough to warrant the use of bibliometric analysis, while any collection lower than 300 papers is deemed "an overkill". Figure 1 shows outlined the protocol used in gathering the targeted data set on spatial literacy in this study.

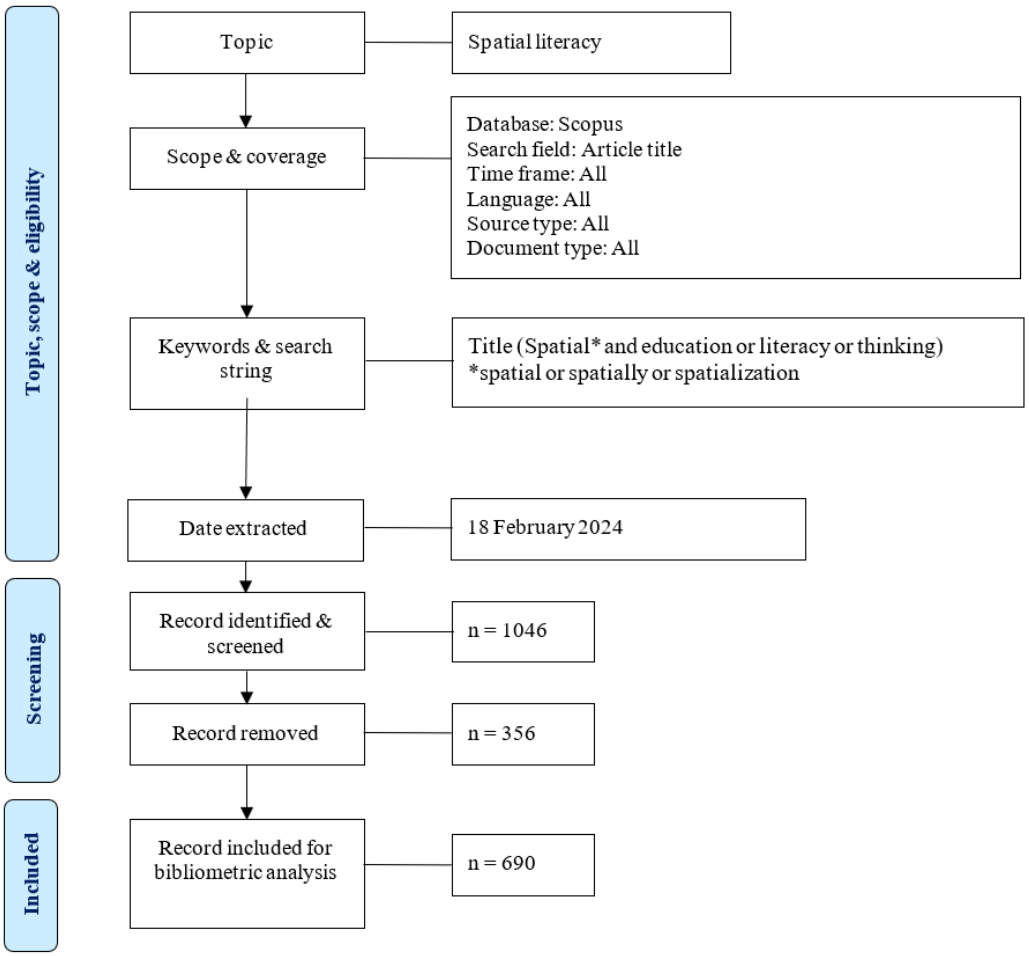

Figure 1. Flow diagram of the search strategy.

Source: Zakaria et al. (2021).

3.2. Data Analysis

To address the research questions (RQ), the publications obtained from the Scopus database were filtered based on several indicators as listed here,

RQ1: How is the development and distribution of research on spatial literacy over time? Publication trend, Document profiles, and Publications by source title.

RQ2: What are the essential themes and topics that have emerged in spatial literacy research? Subject matter, Top keywords, and co-occurrence analysis of author's keywords

RQ3: Who are the key contributors and collaborators in the field of spatial literacy research? Publication by authors, institutions, and countries, citation metrics, highly cited documents, and citation analysis by document and countries.

3.3. Tools

Publication output on spatial literacy research was obtained directly from the Scopus '*analyze all search result*' function, which presents publication data in the form of charts. Content analysis utilized the Scopus '*export refine*' function to export information, including open access, year, author name, subject area, document type, publication stage, source title, keyword, affiliation, funding sponsor, country, source type, and language to a new Excel file. A second Excel file was created using the *all results* function in Scopus to delve deeper into the bibliometric structure, by calculating percentages and rankings.

Publication impact analysis employed *Harzing's Publish or Perish* software to calculate the citation metric, *h-index* and *g-index*. *VOSviewer* software facilitated citation network analyses by visualizing links among the most relevant author keywords, citation links by document and country, and co-citation by cited authors.

4. RESULTS

In addressing the research questions (RQ) posed in this study, an extensive analysis of publications sourced from the Scopus database was conducted, employing a multifaceted approach to unravel the intricate landscape of spatial literacy research. Our investigation delved into three distinct research inquiries:

4.1. RQ1: Development and Distribution of Research on Spatial Literacy Over Time

4.1.1. Publication Trends

Figure 2 displays the total number of publications related to spatial literacy, amounting to 690 works spanning the years from 1930 to February 2024. In the early years, there was a modest production of publications in the field of spatial literacy.

However, a notable increase occurred in the 2000s, followed by a general upward trend until 2023, reaching a peak of 65 productions in 2022. The number of publications has been consistently high in recent years, with 57 publications in 2021 and 70 publications in 2022 amidst a decline in 2023. This trend suggests that there has been a growing interest in the topic of spatial literacy among researchers, and highlights the importance of this field in education, psychology, geography, and other related disciplines.

Table 1 further illustrates this connection.

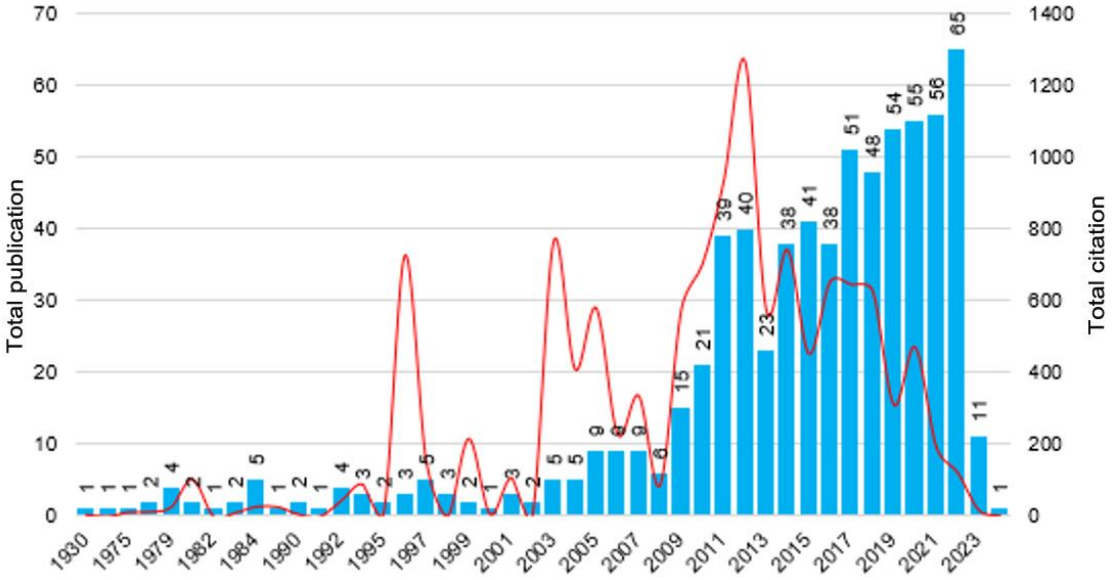

Figure 2. Total publications and citations by year.

Table 1. Year of publication.

Year	TP	NCP	TC	C/P	C/CP	h	g
1930	1	1	5	5.00	5.00	1	1
1959	1	0	0	0.00	0.00	0	0
1975	1	1	12	12.00	12.00	1	1
1978	2	2	13	6.50	6.50	2	2
1979	4	3	26	6.50	8.67	3	4
1980	2	2	104	52.00	52.00	2	2
1982	1	0	0	0.00	0.00	0	0
1983	2	1	10	5.00	10.00	1	2
1984	5	3	27	5.40	9.00	2	5
1989	1	1	27	27.00	27.00	1	1
1990	2	2	6	3.00	3.00	1	2
1991	1	0	0	0.00	0.00	0	0
1992	4	2	44	11.00	22.00	2	4
1993	3	2	90	30.00	45.00	2	3
1995	2	2	10	5.00	5.00	2	2
1996	3	2	727	242.33	363.50	2	3
1997	5	4	152	30.40	38.00	3	5
1998	3	1	1	0.33	1.00	1	1
1999	2	2	217	108.50	108.50	2	2
2000	1	1	7	7.00	7.00	1	1
2001	3	2	108	36.00	54.00	2	3
2002	2	1	5	2.50	5.00	1	2
2003	5	4	767	153.40	191.75	3	5
2004	5	4	410	82.00	102.50	4	5
2005	9	6	580	64.44	96.67	5	9
2006	9	6	229	25.44	38.17	5	9
2007	9	9	336	37.33	37.33	4	9
2008	6	6	87	14.50	14.50	6	6
2009	15	12	576	38.40	48.00	9	15
2010	21	18	703	33.48	39.06	11	21
2011	39	34	935	23.97	27.50	15	30
2012	40	37	1267	31.68	34.24	15	35
2013	23	20	575	25.00	28.75	10	23
2014	38	35	743	19.55	21.23	15	26
2015	41	31	453	11.05	14.61	12	20
2016	38	33	654	17.21	19.82	15	25
2017	51	44	646	12.67	14.68	15	24
2018	48	39	629	13.10	16.13	12	24

Year	TP	NCP	TC	C/P	C/CP	h	g
2019	54	35	311	5.76	8.89	11	16
2020	55	46	472	8.58	10.26	13	19
2021	56	40	193	3.45	4.83	8	11
2022	65	38	123	1.89	3.24	6	7
2023	11	9	18	1.64	2.00	2	3
2024	1	1	2	2.00	2.00	1	1
Total	690	542	12300	1222	1558.33	229	389

Note: TP=Total number of publications; NCP=Number of cited publications; TC=Total citations; C/P=Average citations per publication; C/CP=Average citations per cited publication; h=h-index; and g=g-index.

Table 1 displays the citations per publication and per cited publication, with the highest recorded metric of 242.33 and 363.50, respectively, in 1996. This particular year marked the launch of MapQuest, a web-based mapping service, and the release of Global Positioning System (GPS) software for consumer use. Both citation metric showed an increase of 108.50 each in year 1999 with the introduction of ArcGIS by ESRI, widely used in various applications such as urban planning, natural resource management, and disaster response.

In 2003, the average number of times a paper on spatial literacy had been cited in other papers was 153.40, and the average number of citations in a paper that has at least one citation was 191.75. This coincided with the release of Google Earth and GPS-enabled smartphones, allowing users to access location-based services and applications on their mobile devices. However, both citation metric showed a steady decline with minor fluctuation in certain years after 2003.

The h-index and g-index values indicate a steady growth in the impact and productivity of spatial literacy research over the years, reaching a peak in the early 2010s. The h-index, which measures the productivity and impact of spatial literacy research based on the number of publications and their publication frequency, achieved its highest value at 15 in 2012. Similarly, the g-index, a variant considering the distribution of citations across spatial literacy publications reached its peak value of 35 in the same year. Notably the h-index and g-index values are not evenly distributed across the years. A significant increase in both h-index and g-index values was observed in 2009 compared to the preceding years. This suggests the possibility that there may have been breakthroughs or major contributions to spatial literacy research in the years after, especially in the field of geospatial visualization and analysis related to spatial technology.

4.1.2. Documents Profiles

The dataset in Table 2 provides information on the 690 publications on spatial literacy research across five different source types from Scopus. The purpose of this analysis is to provide insights into the distribution of publications by source type and to identify the most prevalent types of publications in this field. The majority of publications were published in journals (n = 470; 68.12%), followed by conference proceedings (n=143; 20.72%). A smaller proportion of publications was in books (n=50, or n=7.25%) or book series (n=26; 3.77%), and only 1 publication (n=0.14%) were in trade journals. Although trade publications are the least, they are indexed in Scopus as Elsevier executes inclusion of different source types to provide better content coverage of bibliographic literature (Pranckutė, 2021).

Table 2. Source type.

Source type	Total publications (TP)	Percentage (%)
Journal	470	68.12
Conference proceeding	143	20.72
Book	50	7.25
Book series	26	3.77
Trade journal	1	0.14
Total	690	100.00

The predominant types of documents in the publications of spatial literacy research consist of articles, totaling 416 or 60.29% of the total publication. Conference papers come second, with 156 publications (n=22.61%). Book chapters contributed 7.39% of the total with 51 publications, while reviews accounted for 5.22% with 36 publications. Notes and books make up 1.59% and 1.16%, contributing 11 and 8 publications, respectively. Editorials represented 1.01% with 7 publications, while erratum (n=3), letters (n=1), and short surveys (n=1), each have a percentage less than 1%. Overall, the data indicates that articles and conference papers constitute the majority of spatial literacy research publication, together representing over 80% of the total publication.

4.1.3. Publications by Source Titles

The Journal of Geography, published by Taylor & Francis, leads with the highest number of publications at 22 (3.19% of total), followed by IOP Conference Series Earth and Environmental Science and Journal of Physics Conference Series, both published by IOP Publishing (UK), with 16 (n=2.32%) and 14 (n=2.03%) publications respectively. Other journals with a notable number of publications include the Journal of Geography in Higher Education (n=10 publications, n=1.45%), American Society for Engineering Education (ASEE) Annual Conference and Exposition Conference Proceedings (n=9; n=1.30%), WS.org (CEUR) Workshop Proceedings (n=9; n=1.30%), Procedia Social and Behavioral Sciences (n=9; n=1.30%), and Cognitive Research Principles and Implications (n=8; n=1.16%). The remaining publications were distributed among various journals, conference proceedings, reviews, lecture notes, each with five or fewer publications, collectively amounting to less than 1% each of the total. The publishers of these diverse journals and conference proceedings include Springer, Elsevier, Association for Computing Machinery (ACM), Frontiers Media, Routledge, Geological Society of America, Eyup Artvinli, and M. Jeusfeld c/o Redaktion Sun SI.

4.2. RQ2: Emergent Themes and Topics in Spatial Literacy Research

4.2.1. Subject Area

The largest subject area in the research of spatial literacy is Social Sciences, which represents 61.16% (n=422) of the total publications. This is more than three times larger than the second-largest subject area, Computer Science. Computer Science, and Earth and Planetary Sciences are the second and third largest subject areas, respectively, with 18.99% (n=131) and 16.23% (n=110) of the total publications. Psychology and Engineering round out the top five subject areas, each representing 14.49% (n=100) and 12.75% (n=88) of the total publications, respectively. There is a significant drop-off in the number of publications for subject areas beyond the top five, with each subsequent subject area representing less than 10% of the total publications.

4.2.2. Top Keywords

The most common keyword authors used in the publications of spatial literacy is "Spatial Thinking," which appears in 157 publications, representing 22.75% of the total publications. "Student/Students" is the second most preferred keyword, appearing in 111 publications (16.09%), followed by "Human/Humans," in 97 publications (14.06%). This is followed by the geospatial software "Geographic Information Systems/GIS" (n=80;11.59%). The next most frequently used author's keywords are related to spatial skills and abilities, such as "Spatial Ability/Abilities" (n=57; 8.26%) and "Spatial Analysis" (n=52; 7.54%). Other frequently occurring author's keywords include words related to education and teaching, such as "Education" (n=65; 9.42%), "Teaching" (n=44; 6.38%), and "Curricula/Curriculum" (n=41; 5.94%). Gender-related keywords, "Male" (n=30; 4.35%) and "Female" (n=28; 4.06%), imply that gender is a significant focus in the publications. "Virtual Reality" and "Augmented Reality" (n=18; 2.61% and n=16; 2.32%) publications, respectively) appear in the list, which may indicate that the use of these technologies in spatial thinking research is gaining attention.

4.2.3. Co-Occurrence Analysis of All Keywords

Figure 3 illustrates the results of a VOSviewer co-occurrence analysis with full counting on all keywords with a minimum of 5 occurrences for each keyword. From a total of 3078 keywords, 174 met the 5 occurrences criteria and for each of the keywords. For each of the 174 keywords, the total strength of the co-occurrence links with the other keywords was calculated, and the keywords with the greatest total link strength were selected and displayed here. 5 cluster were created with major cluster named spatial (n=76), spatial education (n=44), human or human's spatial perception (n=42), medical (n=11) and cognitive development (n=7). Spatial thinking was the major co-occurrence keywords among all the keywords and all related spatial abilities in the field of education were highly popular.

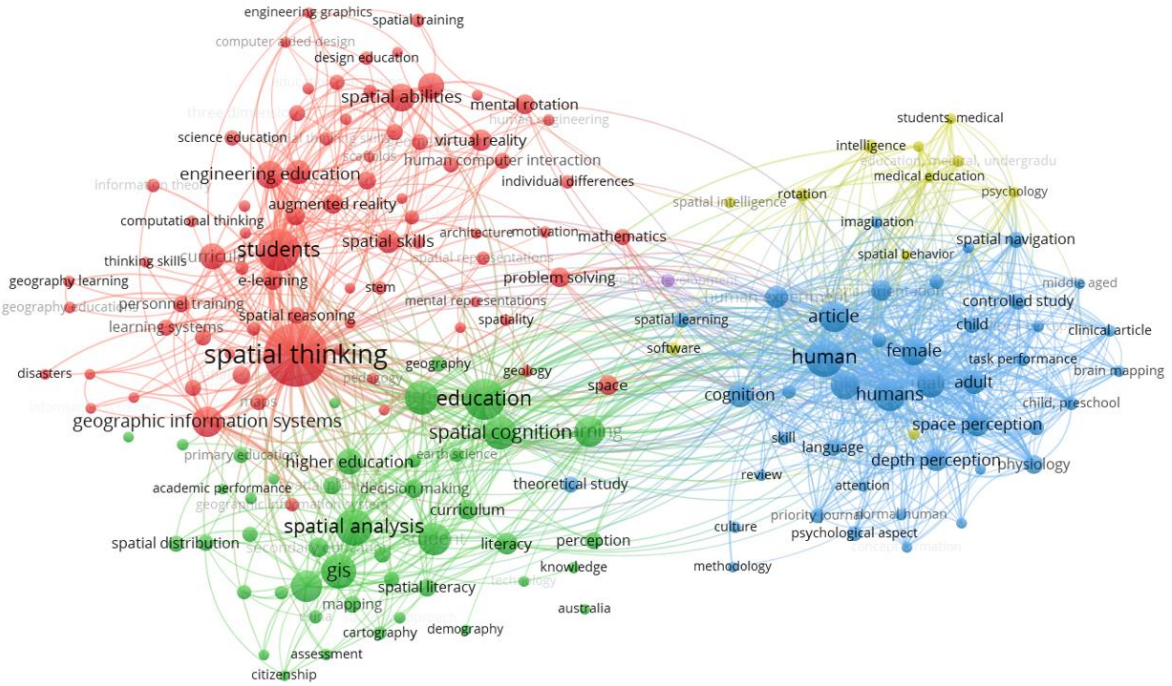

Figure 3. Network visualization map of author keywords with at least 5 occurrences.

4.3. RQ3: Key Contributors and Collaboration in Spatial Literacy Research

4.3.1. Publications by Authors

The Table 3 includes the ten most productive authors of spatial literacy research with 7 out of them affiliated to institutions from the United States. Newcombe, N.S. stands out with the highest number of publications (13) and the highest number of cited papers (12), accumulating a high number of total citations (696) but her average citations per publication (n=53.54) and per cited publication (n=58) are relatively lower compared to Uttal, D H who has the highest number of average citations per publication (n=90.14) and per cited publication (n=105.17), indicating a substantial impact of his publications. Bednarz, R. also demonstrates high average citations per publication (n=74.5) and per cited publication (n=89.40). The h-index and g-index of the authors range from 4 to 10 and from 6 to 13, respectively. The h-index measures the impact of an author's publications, considering both the number of publications and their citations. The g-index is a variant of the h-index that gives more weight to highly cited publications. While most of the authors have a relatively low number of publications and citations, some authors have made a significant impact with their research, evident in their high citation rates and indexes.

Table 3. Most productive authors.

Author's name	Affiliation	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*
Newcombe and Frick (2010)	Temple University	United States	13	12	696	53.54	58.00	10	13
Hegarty (2011)	University of California	United States	10	9	432	43.20	48.00	7	10
Bednarz and Kemp (2011)	Texas A&M University,	United States	8	8	140	17.50	17.50	7	8
Stieff, M.	University of Illinois at Chicago	United States	8	7	169	21.13	24.14	5	8
Handoyo, B.	Universitas Negeri Malang	Indonesia	7	7	49	7.00	7.00	5	7
Ishikawa, T.	Toyo University,	Japan	7	6	231	33.00	38.50	6	7
Jo, I.	Texas State University	United States	7	7	164	23.43	23.43	7	7
Uttal, Miller, and Newcombe (2013)	Northwestern University	United States	7	6	631	90.14	105.17	6	7
Bachri, S.	Universitas Negeri Malang	Indonesia	6	6	50	8.33	8.33	4	6
Bednarz and Kemp (2011)	Texas A&M University,	United States	6	5	447	74.50	89.40	5	6

Note: TP=Total number of publications; NCP=Number of cited publications; TC=Total citations; C/P=Average citations per publication; C/CP=Average citations per cited publication; h=h-index; and g=g-index.

4.3.2. Publications by Institutions

Table 4 indicates that The University of California, the United States is the major contributor to spatial literacy research, with the highest total number of publications (n=20) and total citations (n=1426). With an average of 71.30 citations per publication and an average of 83.88 citations per cited publication the university demonstrates substantial impact. Notably it holds the highest h-index and g-index values of 12 and 20, respectively, indicating a high level of impact and influence in the academic community of this university with 10 campuses. While 11 out of the 16 of the most productive institutions come from the United States, institutes from Asia such as Indonesia (Universitas Negeri Malang; Universitas Pendidikan Indonesia) and Japan (The University of Tokyo), together with Spain (Universidad de la Laguna) and Ireland (University of Limerick) also contributed to the body of knowledge in spatial literacy. Reflecting here a diverse global engagement in advancing the field of spatial literacy.

Table 4. Most productive institutions with minimum of seven publications.

Affiliation	Country	TP	NCP	TC	C/P	C/CP	*h*	*g*
University of California, Santa Barbara	United States	20	17	1426	71.30	83.88	12	20
Temple University	United States	18	17	831	46.17	48.88	12	18
Texas A&M University	United States	15	15	484	32.27	32.27	12	15
Universitas Negeri Malang	Indonesia	13	11	90	6.92	8.18	6	9
Northwestern University	United States	10	9	385	38.50	42.78	7	10
Pennsylvania State University	United States	9	8	241	26.78	30.13	6	9
The University of Tokyo	Japan	8	7	234	29.25	33.43	6	8
University of Illinois at Chicago	United States	8	7	169	21.13	24.14	5	8
Universitas Pendidikan Indonesia	Indonesia	8	4	15	1.88	3.75	3	3
Columbia University	United States	7	7	208	29.71	29.71	5	7
University of California, Santa Barbara	United States	20	17	1426	71.30	83.88	12	20
Temple University	United States	18	17	831	46.17	48.88	12	18
Texas A& M University	United States	15	15	484	32.27	32.27	12	15

Note: TP=Total number of publications; NCP=Number of cited publications; TC=Total citations; C/P=Average citations per publication; C/CP=Average citations per cited publication; h=h-index; and g=g-index.

4.3.3. Publications by Countries

In Table 5, it can be inferred that the United States has the highest productivity and impact in terms of research output, as evident by its large number of publications, high citation count, and elevated h-index and g-index scores. the United States leads in spatial literacy research publications with a total of 253, followed by Indonesia and the United Kingdom, each with 47 publications. Examining both productivity and impact, the h-index indicates the United States has the highest h-index (n=43), followed by the United Kingdom (n=15) and Australia (n=11). Similarly, the g-index, considering citation distribution among publications, places the United States in the forefront with highest g-index (n=75), followed by the United Kingdom (n=34) and Australia (n=23). Figure 4 illustrates further the distribution of the number of publications on spatial literacy research by countries.

Table 5. Top 10 Countries contributed to the publications.

Country	TP	NCP	TC	C/P	C/CP	*h*	*g*
United States	253	36.67%	215	6632	26.21	30.85	43
Indonesia	47	6.81%	31	191	4.06	6.16	9
United Kingdom	47	6.81%	43	1238	26.34	28.79	15
Germany	42	6.09%	32	320	7.62	10.00	10
Australia	39	5.65%	32	553	14.18	17.28	11
China	25	3.62%	18	250	10.00	13.89	8
Spain	24	3.48%	17	300	12.50	17.65	10
Canada	20	2.90%	16	284	14.20	17.75	8
Turkey	18	2.61%	14	694	38.56	49.57	6
Japan	17	2.46%	15	290	17.06	19.33	9

Note: TP=total number of publications; NCP=number of cited publications; TC=total citations; C/P=average citations per publication; C/CP=average citations per cited publication; h=h-index; and g=g-index.

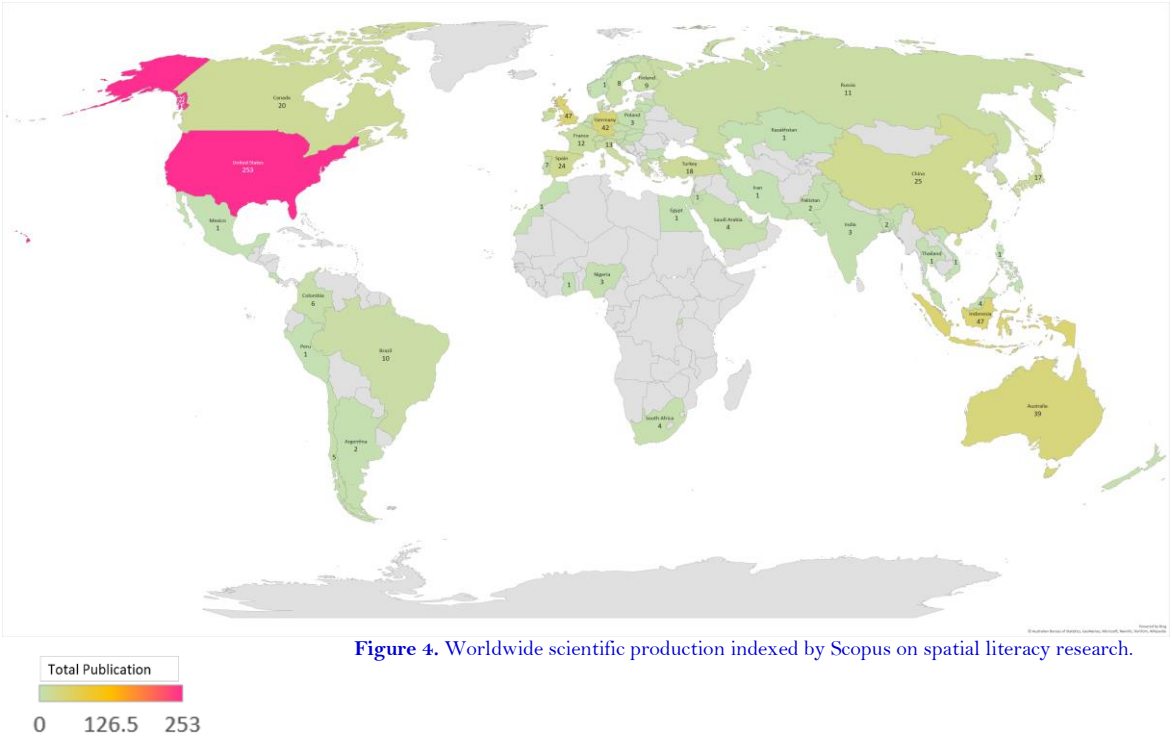

Figure 4. Worldwide scientific production indexed by Scopus on spatial literacy research.

4.3.4. Citation Metrics

In Table 6, the citation metrics for 690 spatial literacy papers reveal a combined citation count of 12,300 spanning a 94 years period with an average of 130.85 citations per year. The average number of citations per paper is 157.85, while the average number of citations per author is significantly higher at 6865.98 indicating that some

authors have published multiple papers with high citation counts. On average, each author has published 369.44 papers on spatial literacy, and each paper has 2.67 authors.

The h-index indicates that the 52 most highly cited papers have each been cited at least 52 times and the g-index accounts for the distribution of citations among publications is 93. This suggests that the 93 most highly cited papers account for the majority of the overall citation count. Overall, the data suggests that the papers have made a significant impact, evidenced by a high number of citations per year and per paper.

Table 6. Citations metrics.

Metrics	Data
Papers	690
Citations	12300
Years	94
Cites_year	130.85
Cites_paper	17.83
Cites_author	6865.98
Papers_author	369.44
Authors_paper	2.67
h_index	52
g_index	93

4.3.5. Highly Cited Documents

Table 7 displays a list of the nineteen documents that have been cited the most frequently in the field of spatial literacy. Two of the most influential documents by Kita and Özyürek (2003) and Shah and Miyake (1996) delved into the intricate relationship between spatial information and verbal or language processing, which involves cognitive resources. These two main themes persist in the work of Alibali (2005); as well as Pruden, Levine, and Huttenlocher (2011) and Zebian (2005). Other frequently cited documents explore the intersection of spatial literacy with STEM education, spatial thinking and geographical studies.

Table 7. Most influential documents with a minimum of 100 citations per document.

No.	Authors	Title	Cites	Cites per year
1	Shah and Miyake (1996)	The separability of working memory resources for spatial thinking and language processing: An individual differences approach	713	25.46
2	Kita and Özyürek (2003)	What does cross-linguistic variation in semantic coordination of speech and gesture reveal? evidence for an interface representation of spatial thinking and speaking	619	29.48
3	Uttal and Cohen (2012)	Spatial thinking and STEM education when, why, and how?	359	29.92
4	Zebian (2005)	Linkages between number concepts, spatial thinking, and directionality of writing: The SNARC effect and the REVERSE SNARC effect in English and Arabic monoliterates, biliterates, and illiterate Arabic speakers	293	15.42
5	Pruden et al. (2011)	Children's spatial thinking: Does talk about the spatial world matter?	269	20.69
6	Thrift (2004)	Movement-space: The changing domain of thinking resulting from the development of new kinds of spatial awareness	263	13.15
7	Alibali (2005)	Gesture in spatial cognition: Expressing, communicating, and thinking about spatial information	251	13.21
8	Mathewson (1999)	Visual-spatial thinking: An aspect of science overlooked by educators	211	8.44
9	Uttal et al. (2013)	Exploring and enhancing spatial thinking: links to achievement in science, technology, engineering, and mathematics?	204	18.55
10	Newcombe and Frick (2010)	Early education for spatial intelligence: Why, what, and how	181	12.93

4.3.6. Citation Analysis by Countries

Figure 5 illustrates the citation network of spatial literacy research by country, revealing the patterns of citation between researchers from different countries, with each document having a maximum of one country and a minimum of one document per country. For each of the 68 countries selected, the total strength of the citation links with other countries was calculated and 42 countries with the greatest total link strength were selected and displayed here. The results of citation analysis shows that the United States of America holds the greatest strength and had citation across many countries from different continents. Other notable citation links were contributed by Indonesia, the United Kingdom, and Germany.

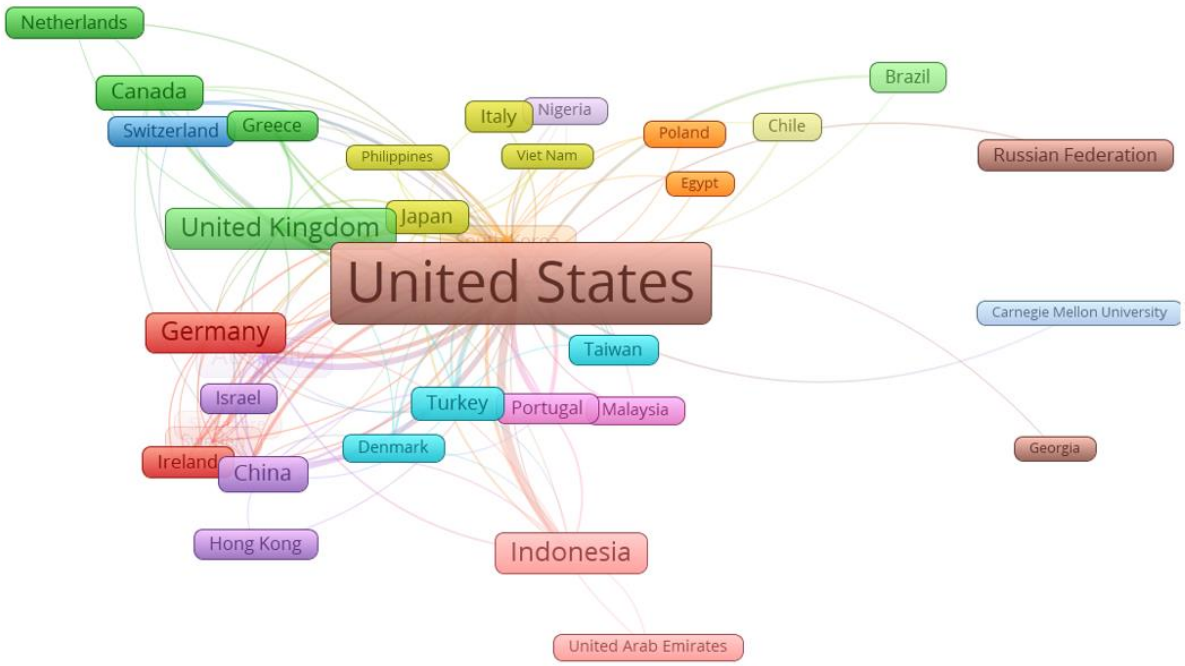

Figure 5. Network visualisation map of the citation by countries.

5. DISCUSSION

Bednarz and Kemp (2011) identified a gap in empirical evidence concerning the characteristics, nature, and development of spatial literacy. Despite this deficiency in empirical evidence, the progression of technology, particularly in geospatial information and computing science, has resulted in a proliferation of publications on spatial literacy. Researchers have employed diverse approaches to measure various facets of spatial cognition. However, the use of different spatial tasks across studies presents challenges in comparing findings (Solem et al., 2015). In this study, a bibliometric analysis is used to quantify the extensive scope of spatial literacy research from a database that has grown extensively since 1930. Drawing from a collection of 690 scholarly works on spatial literacy from Scopus, this analytical approach aims to provide a comprehensive understanding of the historical trajectory (RQ1), thematic landscape (RQ2), and key contributors shaping the field of spatial literacy research (RQ3).

To address the first question (RQ1), a performance analysis based on publication-related metric, such as total publications and citation, the productivity of active years of publications, document profiles and publications by source title, was conducted. Spatial literacy research originated in 1930 with one publication and another in 1959. It then showed a steady, albeit small, increase from the 1970s to 2000s. Interest in spatial thinking grew among researchers in the 2010s, and the number of publications has remained consistently high since. The citations analysis also indicated improvement, with some fluctuations reaching their highest values for both metrics in 1996, 2003, and 2012. These peaks are closely related to the advancement of geospatial technologies, emphasizing the

significance of spatial ability to visualize two-dimensional data into three-dimensional reality and vice versa. Publications on spatial literacy increased and were highly cited, coinciding with the introduction of MapQuest and GPS software like Garmin StreetPilot, ArcGIS by Environmental Systems Research Institute, Inc. (ESRI), and consumer tools like Google Earth, and GPS-enabled smartphones like Google Map and Waze. These technological advancements played a significant role in driving research and innovation in spatial literacy, contributing to the recognition of spatial literacy as an important area of study.

RQ2 aims to uncover the essential themes and areas of focus that have been prevalent in the field of spatial literacy through the examination of major subject matter, top keywords, and co-occurrence analysis of all keywords. The analysis of subject areas and keywords provides intriguing insights into the thematic landscape of the literature on spatial literacy. The results show that the dominant subject area in spatial research is the social sciences, with a primary focus on education (Logan, 2012). 'Spatial Thinking' emerged as the predominant keyword, reflecting the central focus and emphasis placed on this fundamental aspect of spatial cognition. The prevalence of this term suggests a concerted effort among authors to delve into the intricacies of how individuals perceive and navigate spatial information. The prevalence of keywords such as 'Student/Students 'and 'Human/Humans' implies a keen interest in understanding the development of spatial thinking develops and its impact on human interaction, particularly among students, within their surroundings. The inclusion 'Geographic Information Systems/GIS, 'Education' 'Teaching', 'Spatial Cognition', 'Curricula/Curriculum', and 'Geography Education' as prominent keywords highlights the intersection of technology and pedagogy in the spatial literacy discourse. Spatial Ability/Abilities', 'Spatial Analysis' signify the attention given to the assessment and analysis of spatial skills. Researcher seem keen on not only understanding the nature of spatial abilities but also on developing effective methods for evaluating and enhancing these skills. Many studies have investigated spatial thinking among students, using various tasks to assess their spatial abilities, such as navigation, mapping, STEM, geography, language and robotic (Bikar et al., 2022; Gulson & Symes, 2007; Mathewson, 1999; Newcombe & Frick, 2010; Uttal & Cohen, 2012; Uttal et al., 2013). This dual focus reflects a holistic approach towards advancing spatial literacy.

To ascertain the leading contributors and collaborators in the field of spatial literacy research (RQ3), an analysis was conducted to identify the major publication by authors, institutions and countries in spatial literacy. Additionally, a citation analysis was performed to assess the impact of spatial literacy articles by determining their frequency of citation (McBurney & Novak, 2002). The objective is to gain insights into the key individuals, institutions, and countries actively involved in collaborative research within the spatial literacy domain. The results reveal that the top three most productive and highly cited authors are Newcombe, N.S. from the Temple University, Hegarty (2011) from the University of California, and Bednarz and Kemp (2011) from the Texas A&M University. These authors also have the highest co-citation link among researchers in the spatial literacy domain and are affiliated with the most productive institutions in the United States. In Figure 4, spatial literacy research is depicted as receiving considerable global attention, with the United States leading as primary contributor (n=36.7%) in this field. Other notable contributors include countries from different regions, such as Europe (The United Kingdom, Germany, and Spain) Asia (Indonesia, China, and Japan), as well as Australia and Canada. The United States also exhibit the greatest citation strength, with citation originating from many countries across different continents. Notable citation links were observed from countries such as Indonesia, the United Kingdom, and Germany. Despite being a developing country, Indonesia has made a considerable contribution to the study of spatial literacy since 2016. The Indonesia government has actively supported research on spatial thinking, particularly among students. The taxonomy of spatial thinking is incorporated within Indonesia's education curriculum called the 2013 Curriculum Document, which categorizes spatial knowledge competencies and skills together with the effective use of geospatial technology (Ridha & Annaba Kamil, 2021).

However, it must be noted that this study exclusively utilised the bibliographic database from Scopus, excluding other peer-reviewed literature sources such as Web of Science or PubMed. Secondly, due to the ongoing

increase in the publication of spatial literacy research, it is challenging to extrapolate these findings and generalize the results. It is hoped that a more comprehensive search, incorporating both qualitative and qualitative aspects, will be conducted across all well-known scientific databases in the field of spatial literacy for future analyses. This expanded analysis would significantly contribute to a better understanding of how spatial cognition is measured and evaluated. Additionally, it would provide insights into the broader implications of spatial literacy research and foster the development of spatial thinking.

This bibliometric study provides a comprehensive overview of the current state of spatial literacy research, serving as a valuable resource for researchers and practitioners. The outcomes of this analysis illuminate the increasing global interest in spatial thinking research, emphasizing the heightened recognition of the significance of understanding spatial literacy. While spatial literacy research initially evolved from ethnography studies to controlled experiments in laboratory and real-life environment, there is a broader horizon to explore.

Spatial thinking involves the ability to 'think and reason in, with, and about space' as defined by Bednarz and Kemp (2011). This spatial thinking topology calls for researchers to delve deeper into the characteristic, nature, and development of spatial thinking and spatial reasoning. Research can employ many more methodology to address key questions: (1) What thinking skills are essential for real-world navigation or organizing our kitchen cabinet (think in space)? (2) How do we organize factual information into facts and generalization, such as visualization using maps and charts (thinking about space)? (3) How do we spatialize non-spatial data, using space as a framework to conceptualize problems and find solutions? For example, determining the optimal location for a new retail store by analyzing demographic data overlaid with spatial information on population density, income levels, and competitor locations (thinking with space)? (Bednarz & Kemp, 2011).

6. CONCLUSION

Discussion on bibliometrics has been a persistent force since the 1950s, gaining substantial traction in recent years with the accessibility of scientific databases and bibliometric software (Donthu et al., 2021). This analysis has illuminated trends and research gaps withing the study of spatial cognition, offering a comprehensive overview of the latest research areas in spatial literacy. As we move forward, it is imperative to recognize the practical implications of these findings, considering how they can inform educational practices, policy decisions, and the development of spatial literacy applications. Looking ahead, researchers in spatial literacy might explore new avenues of inquiry or refine methodologies for more nuanced insights. Furthermore, fostering interdisciplinary collaboration and knowledge exchange within the global community can propel the field forward, contributing to the shared goal of advancing spatial literacy research. The identified leading contributors and institutions serve as beacons for potential collaboration and shred initiatives. In summary, this bibliometric analysis not only shed light on the current state of spatial literacy research but also provide a foundation for future exploration and collaboration. By connecting these insights to broader educational goal, we can collectively contribute meaningfully to our increasingly spatially-oriented world.

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