Mapping Academic Landscape of PSVT: R Based on VOSviewer: A Bibliometric Analysis

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Abstract. Spatial ability, a fundamental aspect of human cognition, has been the focus of extensive research, particularly within the Purdue Spatial Visualization Test: Rotations (PSVT: R) framework. This study employs bibliometric analysis to explore the landscape of PSVT: R application research, aiming to address concerns regarding its efficacy, particularly within design disciplines. Through meticulous examination of literature trends, author connections, and scientific output, key insights are revealed. The analysis encompasses 126 articles from Scopus, representing 26 countries and involving 254 authors from 230 organizations. Findings indicate a steady increase in publications, with the United States leading in both production and citations. Collaboration networks among authors and institutions, as well as thematic clusters in keywords, shed light on the evolving research landscape. While the study provides valuable insights, limitations exist in data collection and analysis, suggesting avenues for future research to further enrich understanding and inform decision-making in spatial ability research.

Keywords: spatial ability, PSVT: R, bibliometric analysis, VOSviewer, collaboration networks

1. Introduction

Spatial ability, integral to human cognition since early Homo sapiens, remains a cornerstone of human intelligence [1]. Over the past century, extensive research has delved into defining

and analyzing spatial ability, encompassing various dimensions such as understanding, re-membering, imagining, and reasoning about spatial relationships. Scholars' diverse defini-tions have significantly enriched cognitive and educational psychology, providing valuable insights into human cognitive processes and the multifaceted role of spatial ability across tasks and domains.

Concurrently, the development of spatial ability measurement tools has progressed, with psychometric tests and tasks becoming instrumental in assessing individuals' spatial cogni-tion and processing. Among these tools, the Purdue Spatial Visualization Test: Rotations (PSVT: R) has garnered widespread usage, particularly in STEM disciplines, owing to its robustness, validity, alignment with STEM tasks, and accessibility.

This study seeks to address skepticism surrounding the applicability and efficacy of the PSVT: R, especially within design disciplines. Despite its prevalence, concerns persist among scholars regarding its suitability, stemming from ambiguities in defining spatial abil-ities and variations in application contexts. To tackle these challenges, the research endeav-ors to categorize and synthesize existing literature on PSVT: R application, employing bib-liometric analysis to gain a comprehensive understanding of research trends, author-insti-tution connections, and scientific output across various indicators.

The study's objectives include guiding future research trajectories, offering insights into potential avenues, and aiding decision-making within the field. Leveraging knowledge map analysis as a visual representation tool, the research aims to uncover dynamic developmen-tal patterns and contribute to the advancement of the discipline.

2.   Literature Review

Spatial ability, akin to speech cognition, plays a pivotal role in higher cognitive functions [2]. Galton's research marks the inception of modern spatial competence studies [1]. Despite decades of research on spatial ability's definition and structure, a consensus remains elusive. Various scholars have defined spatial competence from different angles, encompassing un-derstanding, remembering, imagining, and reasoning about spatial relationships. These di-verse perspectives have enriched cognitive and educational psychology, shedding light on human cognition and the role of spatial ability across tasks and domains.

Psychologically, spatial ability denotes the cognitive skill associated with mentally rep-resenting and manipulating objects and their spatial relationships. Its measurement has evolved alongside research, employing psychometric tools and tasks to assess spatial cog-nition. Common methods include spatial ability tests, map reading tasks, three-dimensional puzzles, and visual-spatial working memory assessments.

The Purdue Spatial Visualization Test, pioneered by Guay, remains a cornerstone in spa-tial ability measurement [3]. Its revised version, PSVT: R, designed for individuals aged 13

or older, assesses 3-D mental rotation ability [4]. Widely used in STEM education, especially engineering, the PSVT: R stands out for its inclusion of complex 3-D objects, offering a rigorous assessment of spatial visualization ability [5-7].

While scholars laud the PSVT: R's reliability and alignment with STEM tasks, skepticism persists regarding its universal applicability. Bartlett's study raises questions about gender biases and spatial abilities, suggesting the need for alternative assessment tools, particularly in design disciplines [8]. Despite its popularity, literature reviews on PSVT: R are scarce, emphasizing the urgency for comprehensive bibliometric analysis. Such analysis promises to unveil overarching research trends, identify key contributors, and inform future research directions.

In conclusion, understanding spatial ability's nuances and its assessment tools like PSVT: R is critical for advancing STEM education and related disciplines. Through bibliometric analysis, this study aims to provide insights into PSVT: R research trends, fostering informed decision-making and shaping future research trajectories.

3.   Methods

A. Methodology

Bibliometrics, originating in the early 20th century and formalized as a discipline in 1969 [9], has become a staple in literature analysis [10]. It offers a quantitative approach to reviewing and exploring existing literature within a specific field d [11]. Through bibliometric analysis, detailed information such as authors, keywords, journals, countries, and institutions can be systematically captured, providing insights into a field's development [12]. Modern computational tools, such as VOSviewer, enable the graphical representation and visualization of bibliometric networks, facilitating the identification of collaboration, citation, and co-citation patterns among authors, journals, or keywords [13].

Utilizing VOSviewer (version 1.6.20) in this study, we harnessed its capabilities to construct and visualize bibliometric networks. VOSviewer offers researchers a user-friendly interface and multi-dimensional mapping functionalities, allowing for the exploration and understanding of complex scholarly communication landscapes.

B. Data Source

To ensure comprehensive coverage and authoritative data, Scopus was selected as the primary data source. Scopus is renowned for its extensive coverage of scientific literature, including journals, conference proceedings, and patents, making it well-suited for multidisciplinary research [14]. Its vast repository encompasses a broader spectrum of disciplines compared to the Web of Science, particularly in emerging or interdisciplinary fields.

C. **Data Extraction**

Data extraction was conducted on January 4, 2024, encompassing literature published on or before the year 2023. Using specific keywords, including "PSVT: R," "Purdue Spatial Visualization Test*: Visualization of Rotation*," and "Purdue Spatial Visualization Test*: Rotation*," a tailored dataset was curated from Scopus. Employing the Boolean OR operator, 128 literature records were initially retrieved.

However, to mitigate potential issues with duplication, preprocessing of the data was necessary to ensure the integrity of the analysis. The retrieved results were exported as RIS files from Scopus and imported into Endnote software to identify and eliminate duplicate entries. Following a rigorous review, 126 valid literature records were retained for further analysis, with only the most recent version retained in cases of duplication. Notably, the dataset comprised predominantly English-language papers, with one paper in Spanish.

4. Results and Discussions

A. Descriptive Statistics

We exported 126 articles from Scopus in CSV format and processed them using VOSviewer. These articles, spanning various countries and organizations, were published across 51 journals and referenced 2904 documents from 1660 journals. Fig. 1 displays the temporal distribution of published papers related to applied research using PSVT: R.
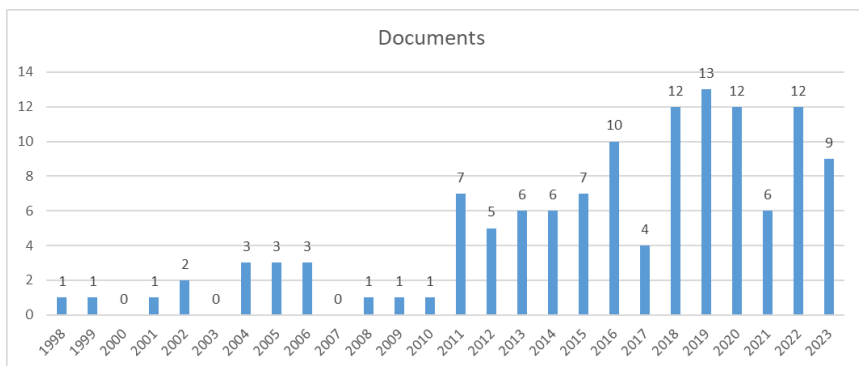

Fig. 1. Time trend of the publications on PSVT: R

In Scopus, the earliest mention of PSVT: R in abstracts dates back to 1998. This study introduced coordinate axes to a section of the PSVT: R for an experimental group, aiming to assess if these axes could improve scores and response times [15].

The number of papers in this field has steadily increased since 2010, peaking in 2019 with 13 papers. Although there was a slight decline in the following years, possibly due to the COVID-19 pandemic, the quantity remained relatively stable. Recent years have witnessed a resurgence, with over 10 papers published annually, indicating sustained interest and application of PSVT: R in spatial ability research.

B.   Bibliometric Analysis of Authors

Analyzing authors provides insights into prominent scholars and core research groups. Price's Law suggests that a small group of highly productive authors typically contributes significantly to the literature output [16]. In this study, 27 core authors collectively published 75 papers, surpassing Price's proposed 50% standard. The collaborative network among these authors, depicted in Fig. 2,   highlights shared research interests and ongoing cooperation, with core authors such as Rodriguez, J., and Van Den Einde, L. playing central roles.

TABLE I.   highlights the most productive and high-quality authors in the field, showcasing their contributions and impact on understanding the importance of spatial visualization and effective educational strategies. Sorby, S. A., Branoff, T. J., and Rodriguez, J. emerge as prolific authors, each focusing on different aspects of spatial visualization research. Sorby underscores the significance of three-dimensional visualization skills for engineering success [17] and has collaborated with 20 scholars. His research encompasses various topics, including the impact of spatial visualization courses, changes in teaching methods, and interventions to enhance spatial skills [18-20]. Branoff's work centers on interventions and the relationship between spatial skills and modeling tasks, providing insights into course outcomes [21-23]. Meanwhile, Rodriguez explores data analysis and course content's influence on spatial visualization, enriching our understanding of effective strategies for enhancing spatial skills through in-depth studies on demographic impacts [24-26]. Yoon, S. Y., and Maeda, Y., on the other hand, stand out as highly cited authors, emphasizing the significance of the Revised PSVT: R and gender differences in spatial abilities [27-30].

TABLE I.   Most important authors in PSVT: R

Author	Docs (r)	Cit. (r)	AC (r)
Sorby	12 (1)	131 (3)	10.9 (63)
Branoff	8 (2))	71 (14)	8.9 (70)
Rodrigue	8 (3)	14 (60)	1.8 (171)
Yoon	5 (6)	277 (1)	55.4 (5)
Maeda	4 (12)	275 (2)	68.8 (4)

Note: "Docs" (Documents) refers to the number of published documents. "Cit." (citations) represents the total number of times documents have been cited. "AC" (Average citations) indicates the average number of citations. "(r)" indicates ranking.
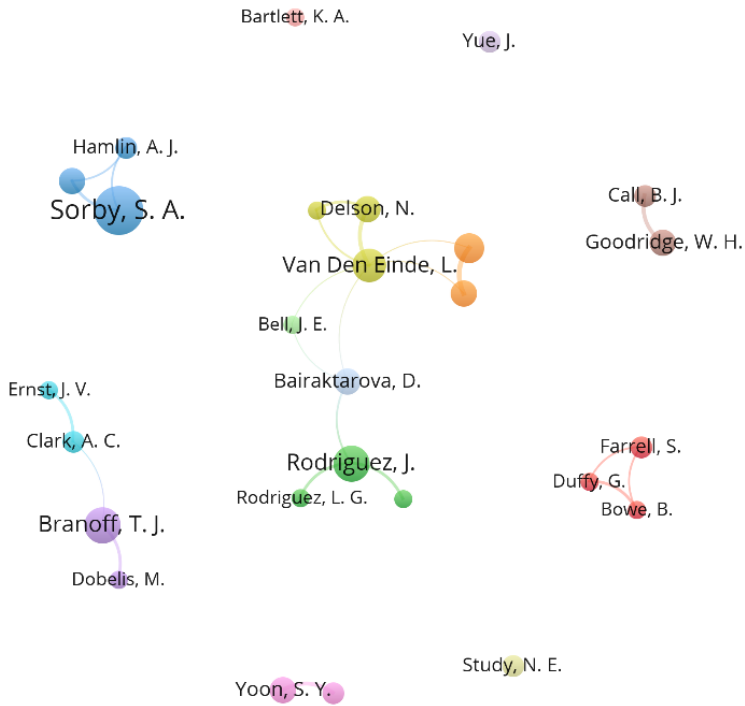
Fig. 2. Core author co-occurrence of PSVT: R

C. Country & Affiliation Bibliometric Analysis

The co-occurrence of countries in the field of applied research on PSVT: R reveals that the United States is at the core of a global collaborative network. TABLE II. ranks countries by publication volume, with the United States leading in both publications and citations. Institutional analysis (TABLE III.) reveals Michigan Technological University and Purdue University as key contributors to PSVT: R research. Through the co-occurrence analysis of countries and institutions, these collaboration patterns and metrics contribute to a deeper understanding of the extent and impact of national and institutional cooperation in the application of PSVT: R in spatial ability research.

TABLE II.   MOST IMPORTANT COUNTRY IN PSVT: R

Country	Docs (r)	Cit. (r)	AC (r)
USA	105 (1)	940 (1)	8.95 (6)
Turkey	4 (2)	123 (2)	30.75 (1)
S. Africa	4 (3)	10 (7)	2.50 (10)

| Spain | 3 (7) | 75 (3) | 25.00 (2) |
| Malaysia | 3 (6) | 41 (4) | 13.67(4) |

TABLE III.   TOP 5 INSTITUTIONS BY PUBLICATION

Affiliation	Docs	Cit.	AC
Michigan Technological Univ.	11	114	10.4
NC State Univ.	9	82	9.1
Purdue Univ.	8	298	37.3
Virginia Polytechnic Institute and State Univ.	8	28	3.5
Western Michigan Univ.	7	14	2.0

D.   Bibliometric Analysis of Journals

Most publications originate from engineering or education journals, with the "ASEE Annual Conference and Exposition" being the top source, reflecting its pivotal role in PSVT: R research. Journals like Educational Psychology Review and Journal of Engineering Education stand out for their high-quality articles and citation impact (TABLE IV.).

Bradford's Law classification suggests a skewed distribution of publications across journals, emphasizing the dominance of certain key sources [31]. However, this distribution does not precisely align with Bradford's Law due to insufficient data and the prevalence of conference papers.

TABLE IV.   MOST IMPORTANT SOURCE IN PSVT: R

Source	Docs (r)	Cit. (r)	AC (r)
ASEE Annual Conference and Exposition	56 (1)	304 (1)	5.4 (24)
Frontiers in Education Conference	8 (2)	44 (9)	5.5 (23)
Engineering Design Graphics Journal	6 (3)	117 (3)	19.5 (9)
Educational Psychology Review	1 (-)	203 (2)	203.0 (1)
Journal of Engineering Education	1 (-)	101 (4)	101.0 (2)
Sustainability	1 (-)	63 (5)	63.0 (3)

E.   Co-occurrence analysis of keywords

Keywords are concise reflections of an article's essence, encapsulating its primary themes. Through co-occurrence analysis, we gain insights into prevalent research areas within the PSVT: R literature. Utilizing VOSviewer, we identified 42 keywords occurring four times or more for analysis and visualization.

Fig. 3 illustrates the density visualization of keywords in PSVT: R literature. Brighter regions indicate higher keyword frequencies, highlighting terms like Spatial Visualization, Students, Engineering Education, Spatial Ability, and Curricula as prominent themes. TABLE V. provides a detailed overview of high-frequency keywords with frequencies exceeding 9.

Further analysis clustered these keywords into distinct groups, as shown in Fig. 4. Cluster 1 (Spatial Visualization and Engineering Education): This cluster focuses on spatial abilities within engineering education contexts. Cluster 2 (Technology and STEM Education): Reflects the intersection of technology, virtual reality, and STEM education. Cluster 3 (Education and Curricula): Emphasizes educational aspects and curriculum development related to spatial abilities. Cluster 4 (Gender Differences and Professional Aspects): Explores gender-specific implications and professional applications of spatial abilities.
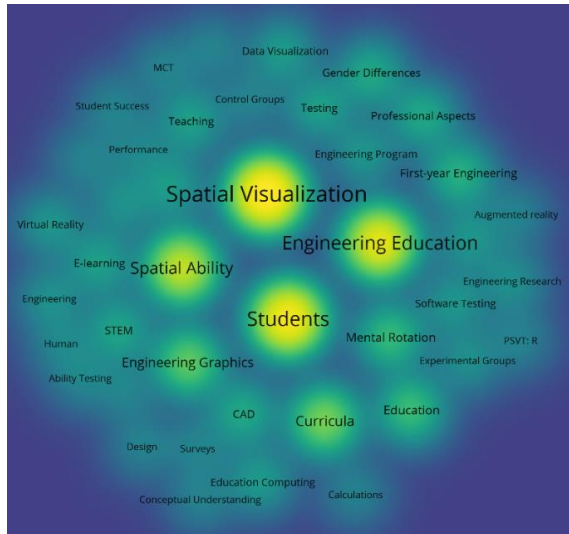
Fig. 3. Density Visualization of Keywords in PSVT: R

TABLE V.   HIGH-OCCURRENCES KEYWORDS IN PSVT: R

Keyword	Occurrences	Total link strength
Spatial Visualization	89	415
Students	74	401
Engineering Education	62	334
Spatial Ability	46	207
Curricula	28	162
Engineering Graphics	23	136
Education	17	108
Mental Rotation	16	74
First-year Students	13	72
Professional Aspects	11	71
Gender Differences	11	47
CAD	11	53
STEM	10	48

Fig. 5 presents an overlay visualization map post-co-occurrence analysis, with colors indicating the average appearance year of keywords. Terms like Spatial Visualization,

STEM, and Engineering Graphics stand out, signifying sustained interest in their relationship with spatial abilities. Emerging themes such as Virtual Reality and Training Program suggest a growing emphasis on immersive technologies and training interventions [32, 33].

In summary, keyword analysis reveals a diverse landscape within PSVT: R literature, guiding future research by identifying key clusters and emerging trends. These insights promote interdisciplinary exploration, particularly in the realms of engineering education, technology, and STEM fields. Additionally, the exploration of gender differences and professional implications offers avenues for research addressing diversity and inclusivity in spatial ability assessments and applications.
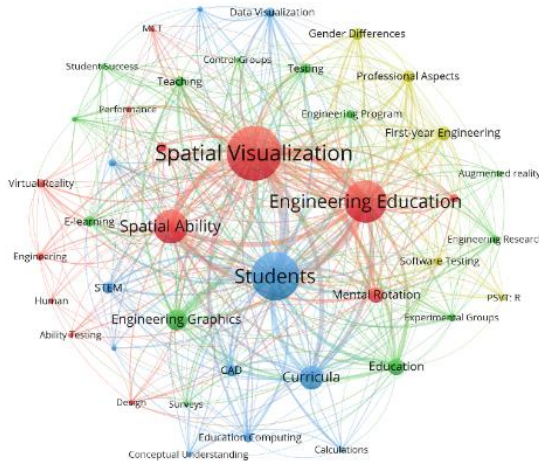
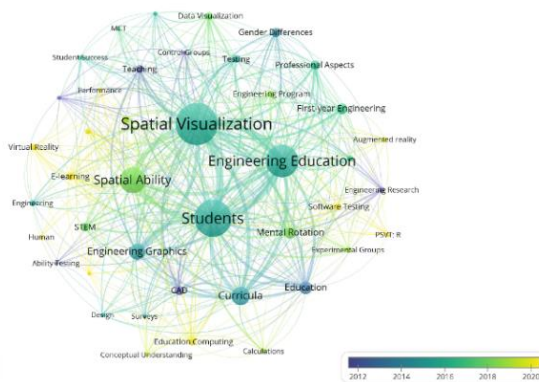Fig. 4. Network visualization of keywords co-occurrence in PSVT: R

Fig. 5. Overlay visualization of keywords co-occurrence in PSVT: R

F. Co-Citation Analysis

Co-citation analysis unveils common citation patterns among documents, aiding researchers in understanding academic domains' structure and key themes.

Co-Citation Analysis of Cited Sources: Out of 1660 cited sources, 51 meet the minimum citation threshold of 8 for analysis. The resulting co-citation network forms four clusters (Fig. 6). Top sources include the "Engineering Design Graphics Journal" and "Journal of Engineering Education," reflecting interdisciplinary research themes. Cluster 1 covers psychology, education, and engineering education journals, emphasizing cognitive abilities and spatial skills. Cluster 2 focuses on engineering and design-related topics. Cluster 3 includes sources from child development and educational psychology journals. Cluster 4 features spatial visualization and educational psychology sources. This analysis highlights interdisciplinary research and cohesive themes within clusters.
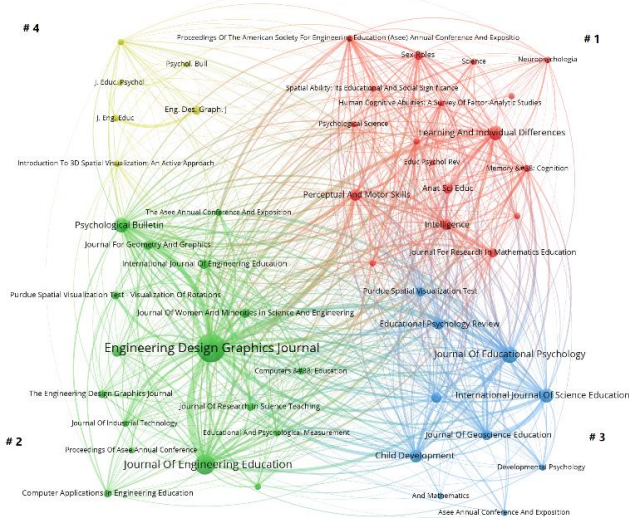

Fig. 6. Co-citation of cited sources

Co-Citation Analysis of Cited References: Among 2904 references, 53 meet the minimum citation threshold of 4. Key references like "Purdue Spatial Visualization Test: Rotations" [3] and "The Development and Assessment of a Course for Enhancing The 3-D Spatial Visualization Skills of First Year Engineering Students" [34] demonstrate significant impact. Meta-analytical studies contribute to understanding spatial abilities across STEM disciplines. This analysis reveals diverse applications and influences of spatial visualization research.
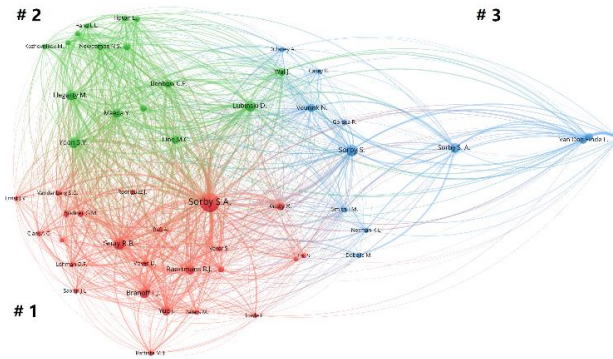
Fig. 7. Co-citation of cited references

Co-Citation Analysis of Cited Authors: Among 4023 cited authors, 52 meet the minimum citation threshold of 13. Sorby, S. A. emerges as the most cited author. Authors are categorized into three clusters (Fig. 7), reflecting collaborative research efforts within specific themes.

In summary, co-citation analysis underscores collaborative and interconnected research in spatial visualization, highlighting authors' contributions to distinct themes.

5. Conclusion and Future Directions

A. Conclusion

This study utilizes bibliometric analysis to explore the landscape of PSVT: R application literature. By meticulously examining authors, keywords, journals, countries, institutions, and references, we aimed to trace the evolution of this field. Leveraging VOSviewer software, our quantitative analysis delved into collaboration, citation, and co-citation patterns among various elements.

Key findings and conclusions from our study include:

We analyzed 126 articles from Scopus, representing 26 countries and involving 254 authors from 230 organizations. The publication trend has seen steady growth, peaking in 2019, with subsequent years showing fluctuations, indicating sustained interest in PSVT: R.

Our author analysis aligns with Price's Law, revealing 27 core authors significantly contributing to the field. Visualization of author collaboration networks underscores the formation of global PSVT: R research teams, with these core authors playing pivotal roles.

A global collaboration pattern, centered on the United States, emerges from country co-occurrence analysis. The United States leads in both publications and citations, with Purdue University as a prominent hub for PSVT: R research.

The "ASEE Annual Conference and Exposition" emerges as the primary venue for disseminating PSVT: R research, highlighting its significance. Noteworthy sources like Educational Psychology Review, Journal of Engineering Education, and Sustainability stand out based on average citation counts.

Keyword co-occurrence analysis reveals clusters focusing on "Spatial Visualization," "STEM," and "Engineering Graphics," indicating sustained interest in spatial abilities within STEM education. The rising emphasis on "Virtual Reality" and "Training Programs" suggests a shift towards immersive technology and innovative training approaches.

Analysis of cited sources underscores the interdisciplinary nature of PSVT: R application, emphasizing cognitive abilities, mathematics education, applied psychology, and spatial skills. Sorby, S.A. emerges as the most cited author, fostering collaborations across various research domains.

B. Limitations and Future Directions

While contributing valuable insights, this study has limitations. Relying solely on Scopus for data collection may lead to incomplete analyses due to data normalization and consistency standards. Additionally, quantitative analysis necessitates a nuanced understanding of the field, introducing subjectivity if researchers lack familiarity.

Looking ahead, future research could address these limitations by incorporating data from multiple sources and integrating qualitative methods to complement quantitative analyses. Exploring emerging trends in PSVT: R research, such as the integration of virtual reality and innovative training programs, could offer valuable insights for educators, policymakers, and researchers involved in spatial ability research.

Acknowledgement

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