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Review and Bibliometric Analysis of Data Literacy in Mathematics Education at Secondary School Level (2012-2024)

E. T. Montso[1], M. Mosia[2] & F. O. Egara[3]*
[1,2,3]Department of Mathematics, Natural Sciences and Technology Education,
University of the Free State, Bloemfontein, South Africa
Corresponding Author: felix.egara@unn.edu.ng

Abstract

In today's data-driven world, integrating data into mathematics education is essential. However, a gap remains between using data for reporting student performance and leveraging it to enhance teaching and learning. This study explores the role of data literacy in mathematics education through a systematic review of 207 papers from Scopus (2009–2024), focusing on secondary school mathematics teaching. Findings reveal an uneven global distribution of research, with South Africa contributing relatively little despite being a leading African nation. Teacher College Record emerges as the most prominent publication source, while Educational Management Administration has the fewest contributions. The study underscores the need to strengthen data literacy, particularly in underrepresented regions like South Africa. Enhancing data-driven decision-making can improve teaching practices and student outcomes. Addressing the global research disparity requires increased international collaboration and efforts to boost contributions from regions with lower representation in data literacy research.

Keywords: Data Literacy, mathematics, mathematics education, school learners, trends in data literacy

Introduction

Education has evolved significantly from traditional methods of imparting knowledge and skills to embracing the digital world, where data literacy has become a crucial skill for both learners and teachers. In today's rapidly changing world, educational institutions must develop mechanisms to equip learners with data literacy skills, which are essential not only for individual advancement but also for societal benefits (Rožman et al., 2023). Data is more than just charts, graphs, and spreadsheets; it plays a central role in our daily lives, influencing how we shape arguments, make decisions, and engage with the world around us (Fontichiaro & Oehrli, 2016).

Data literacy, defined as the ability to collect, analyse, interpret, and critically evaluate data, is indispensable for informed decision-making across various domains of life. In the context of education, data literacy empowers teachers to improve instruction and supports students in building critical thinking skills necessary for cognitive development (Hachmeister et al., 2021; Yan & Li, 2023). Data literacy comprises two components: "data," generally understood to mean numbers or quantifiable information, and "literacy," the ability to use language to describe, discuss, and critically engage with information (Demirtaş, 2024). Together, data literacy involves functional skills for collecting, analysing, and interpreting data to make informed decisions (Demirtaş, 2024; Hachmeister et al., 2021).

At the secondary school level, developing data literacy skills in mathematics is particularly crucial. This stage marks the transition from basic arithmetic to more complex mathematical concepts and applications, making it an opportune time to integrate data literacy into the curriculum. Effective data literacy programs position teachers to make data-driven decisions that enhance instructional quality and student learning outcomes (Demirtaş, 2024). The ability to read and understand different representations of data, draw correct conclusions, and recognize unethical data use is vital for students (Tutkyshbayeva & Zakirova, 2024; Lee et al., 2023; Prado & Marzel, 2013).

Despite its importance, data literacy remains a fluid concept with no universally accepted definition, highlighting the need for further research and consensus (Mertala, 2020; Suryadi et al., 2021). Researchers agree

that data literacy skills are indispensable competencies in the 21st century, making the demand for evidence-based teaching and decision-making apparent in emerging educational research and practices (Braun & Huwer, 2022; Jafari & Safa, 2023). The ability to use data and its applicability is a skill that is becoming more and more important (Kok & Premier, 2023).

In the context of education, data literacy is considered the ability of a teacher to purposefully find, select, filter, collect, analyze, interpret, critique, and visualize data to support arguments using quantitative and qualitative data for implementing instructional actions to improve learning outcomes (Van Audenhove et al., 2020; Atenas et al., 2023; Gray et al., 2018; Suryadi et al., 2021; Vahey et al., 2012). Digital literacy skills are used in education to enhance educational practices, improve teachers' instruction, and support school administration in implementing data-driven interventions aimed at improving teaching and learning outcomes (Gray et al., 2018; Yan & Li, 2023; Hegestedt et al., 2023). The benefits associated with digital systems, such as visualizing learner performance through different sets of graphics, make benchmarking easier and provide tools for aggregating or disaggregating data (Janke et al., 2023). Data literacy has the power to allow teachers to adapt, modify, and develop new knowledge whilst teaching (Sherin, 2002).

Data literacy helps teachers carry out consistent and systematic assessments that support the decision-making process to provide an overview of learners' outcomes. However, teachers often lack the right skills and tools to effectively use data for predicting academic achievement and making informed decisions (Louie, 2022). Zhao (2024) highlights other challenges, including the lack of integration of ICT in practical teaching and weak transformational leadership, which appears to correlate with age. Younger teachers, especially those in urban areas, are more likely to use ICT in teaching compared to their counterparts in rural areas. Data has proven effective in improving academic achievement for students with or at risk for learning disabilities. However, despite its potential, the widespread use of data by educators remains a challenge (Fry et al., 2023). This gap highlights the need for targeted professional development and support systems to enhance teachers' data literacy capabilities (Mohseni et al., 2023; Mandinach, 2012).

Rationale for the Study

Despite the growing importance of data literacy in education, there is a notable lack of comprehensive bibliometric studies that synthesize the existing research on data literacy, particularly in the context of secondary school mathematics. This study addresses this gap by providing a detailed bibliometric analysis of research published between 2012 and 2024. By mapping trends, patterns, and novelties in the literature, this study aims to identify underexplored areas and direct future research efforts. Such an analysis is essential for guiding the development of data literacy programs that are both evidence-based and contextually relevant to secondary education.

Theoretical Framework

This study is grounded in a conceptual framework that combines elements of data literacy and mathematics education. By drawing on established educational theories and data literacy models, the study aims to provide a structured analysis that links the findings to broader pedagogical practices. This framework not only supports the identification of trends in the literature but also enriches the discussion by situating the findings within a coherent theoretical context.

The current study focuses on the teaching of mathematics in secondary schools and examines the extent to which data literacy and data skills are used by teachers to improve their teaching and student attainment. Despite the importance of digital literacy in the digitized world, there is a need to investigate educational data to determine the effectiveness of learning systems, analyze learners' achievement, and design early warning systems for dropout or failure cases (Nawang et al., 2023; Gebre, 2022). Teacher decision-making during instruction is at the core of the teaching process, argues Näsström et al. (2021). However, these decisions should be grounded in empirical evidence on how students are learning. By conducting a descriptive bibliometric analysis of data literacy in mathematics education from research published between 2012 and 2024, the study aims to identify literature gaps and direct future research in understudied areas.

This study examines the bibliometrics of the keyword "data literacy" as a broad subject and determines how to use "data literacy" in the field of mathematics teaching and learning in secondary schools. Scopus-indexed publications are utilized to collect metadata, while the VOSviewer program serves as a visualization tool. The main objectives of this research are to define trends, patterns, novelties, and future research directions in the field of teaching and

learning mathematics in secondary schools, specifically focusing on data literacy over the last twelve years (2012-2024).

Research Questions

The following research questions framed the research investigation:

1. What is the total volume, geographic distribution, and citations in the data literacy literature pertaining to mathematics teaching in secondary schools?
2. Which researchers and research collaborations have had the greatest impact on the data literacy in secondary school mathematics literature?
3. What sources have had the greatest impact in the data literacy in secondary school mathematics literature?
4. What are the most important topics in the data literacy analysis in mathematics literature?

Methods

A bibliometric study was conducted to review and analyse the existing literature on data literacy in the field of secondary school mathematics. Bibliometric analysis is particularly valuable for identifying and studying different themes and trends within a specific research domain. This approach provides prospective researchers with insights into the impact and scope of the study under investigation, leveraging the ability to collect and analyse large datasets from various databases such as Web of Science and Scopus. The built-in algorithms and quantitative analysis techniques in software like VOSviewer facilitate the handling, organization, analysis, and reporting of bibliometric data in alignment with the research questions (Lim & Kumar, 2024).

Search Strategy

The search strategy followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines. The review was carefully planned, and a range of terms was used to describe the constructs of data literacy to focus the research study in line with the research questions. The search string included terms such as "data literacy" AND "mathematics" AND "secondary school" OR "high school." Scopus was used as the primary database for the search process due to its comprehensive coverage of quality journals that meet international, peer-reviewed standards and are recognized in the scientific community (Braun & Huwer, 2022; Casal-Otero et al., 2023). The search was conducted based on titles, keywords, and abstracts between October 21, 2021, and March 9, 2024.

Inclusion and Exclusion Criteria

The inclusion criteria were set to focus on papers published in English and peer-reviewed. Research articles that addressed the integration of data literacy, the use of data literacy in the teaching of mathematics, teacher training, and the application of data literacy information from assessments were included. Specifically, studies on data-driven decision-making, data-driven teaching practices, and data literacy for improving school management and teaching in secondary schools were considered relevant.

Exclusion criteria included research papers on data literacy in higher education or any other subjects outside the focus of secondary school mathematics. After applying these criteria, a total of 207 articles were included in the final analysis. Figure 1 below shows the PRISMA Flow Diagram for identifying and selecting relevant papers on data literacy in mathematics education at the secondary school level.

Data Extraction and Analysis

The bibliometric analytic methodology, combined with bibliometric visualization tools, was employed for data extraction. VOSviewer software was used to gather, evaluate, and visualize bibliographic data. The analysis included examining and visualizing bibliographic coupling of authors, sources, countries, co-occurrences of author keywords, and institutions.

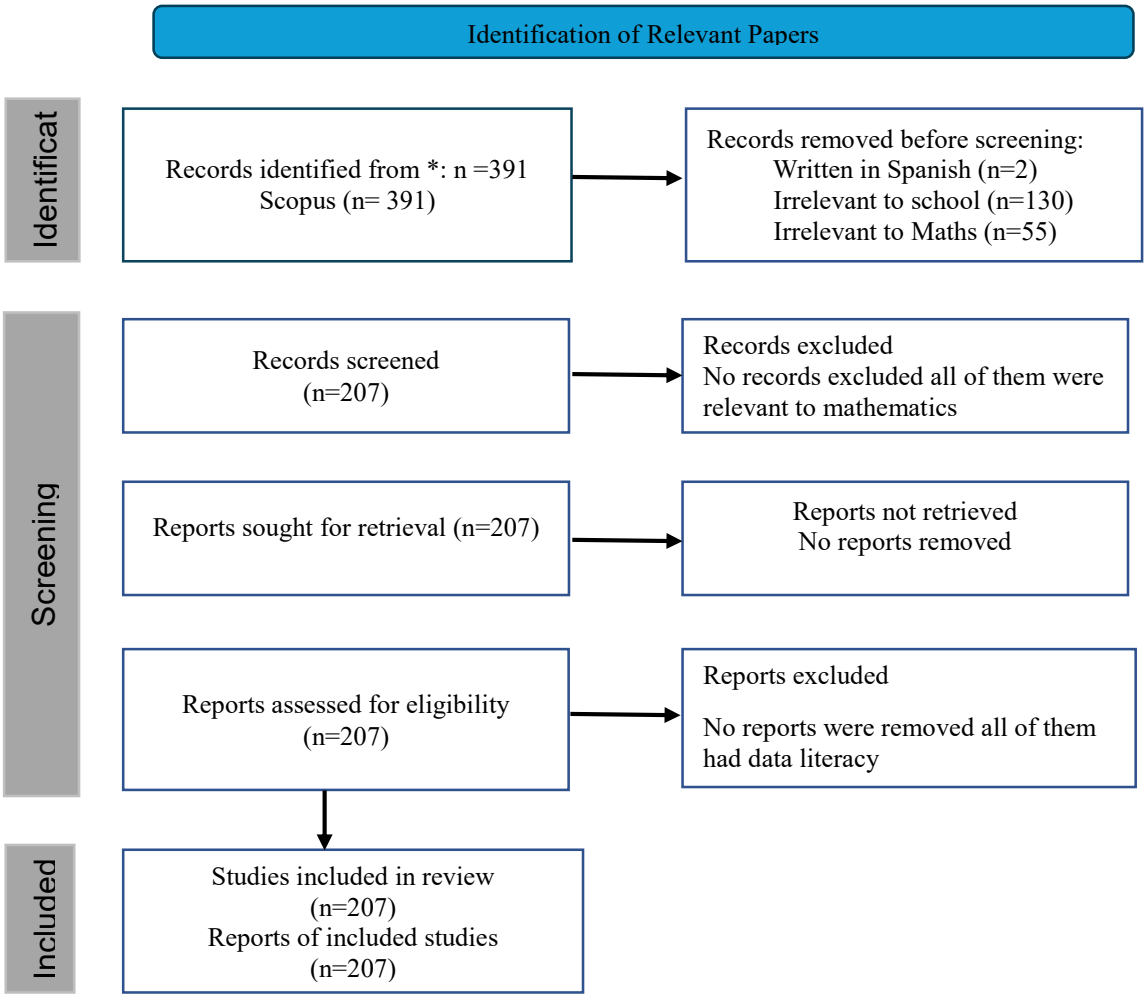

Figure 1. PRISMA Flow Diagram for Selecting Papers on Data Literacy in Secondary School Mathematics Education

Results

This section presents the findings from the bibliometric analysis of data literacy literature in secondary school mathematics education from 2012 to 2024. The results are organized according to the research questions, providing insights into publication volume, geographic distribution, and citation patterns across different regions.

Research Question 1: What is the total volume, geographic distribution, and citations per geographic area in the data literacy literature in Mathematics in Secondary Schools?

To address this question, a fourteen-year analysis of published papers from 2012 to 2024 was conducted, focusing on data analytics. The results are presented in Figure 2 below. The figure illustrates an increase in the number of publications starting from 2012, with one article published that year, peaking at eleven articles in 2021. This was followed by a decline to seven publications in 2022 and an increase to nine publications in 2024. The rise in publications suggests that data literacy usage is influencing teachers and school leaders, which can consequently enhance student learning (Jafari & Safa, 2023).

The sharp increase in publications on data literacy from 2020 to 2021 is attributed to the COVID-19 pandemic, which disrupted the normal schooling regime. Data literacy techniques became an alternative solution to reduce the widening learning gaps due to school closures. These two years saw a significant upsurge in data literacy publications. However, a

noticeable decline in the publication of data literacy articles was observed in 2022 and 2023, contrary to expectations of sustaining the new teaching and learning methods that gained traction during the pandemic.

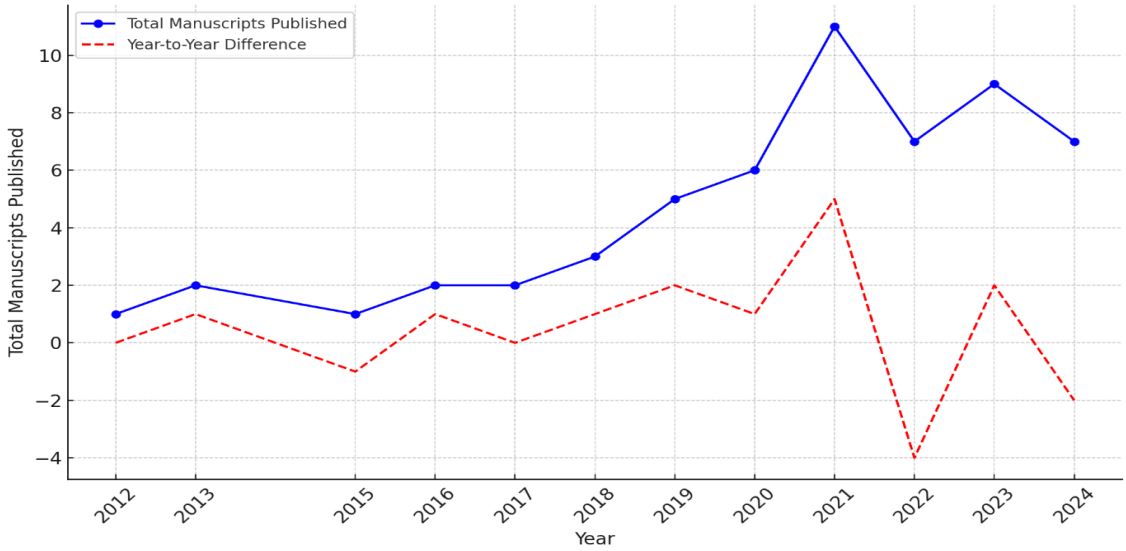

Figure 2. Manuscript Publication Trend Over the Years with Year-to-Year Differences

Pertaining to the geographic distribution of publications related to data literacy, countries with a minimum of five publications and a minimum of ten citations were considered. It is commendable to observe that at least 20 out of 68 countries have met the thresholds of publishing five documents on data literacy with a minimum of ten citations. It can be noted from Figure 3 that the United States, Indonesia, Germany, the Netherlands, and Australia have larger circle diameters than other countries. The most articles in the area of data literacy were published by the United States, totalling 206 publications on data literacy, as reflected in Table 1 below. The United States has published 177 more publications on data literacy than Australia and has 3,374 more citations than Indonesia, which is the second highest in terms of documents published in data literacy. South Africa has published a total of ten data literacy documents with 21 citations. Finland has published five documents on data literacy with 47 citations.

The VOSviewer was used to establish collaboration amongst scholars in the field of data literacy in mathematics education from various countries. Mapping was created to determine co-authorship. Every node in Figure 3 signifies a country contributing to data literacy in mathematics. The size of every node denotes the quantity of publications in data literacy and mathematics education produced by authors in that country. The line linking the two nodes reflects the co-authorship activity of writers from both countries. The broader the line, the more papers were co-authored by various countries. As illustrated in Figure 3, the three most common collaborations are Indonesia-United States, Netherlands-United States-Indonesia, Germany-United States, and Belgium-United States.

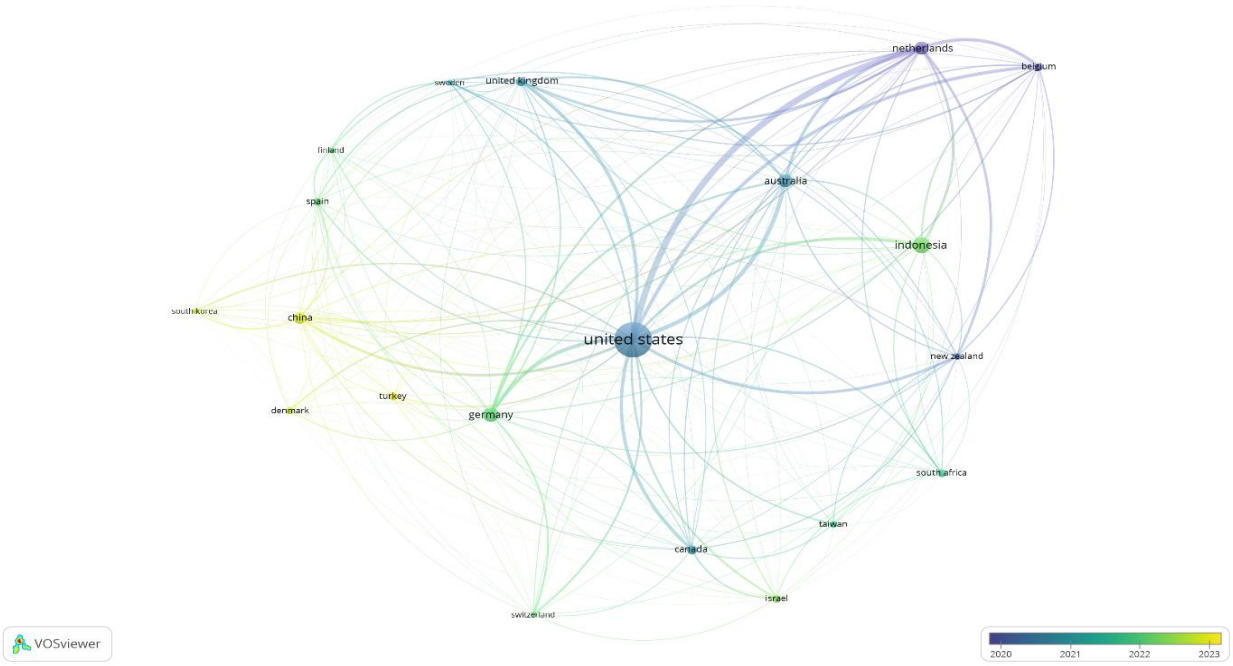

Figure 3. Global Network of Co-Authorship in Data Literacy Publications

Table 1. Top 5 Countries by Publications and Citations in Data Literacy

Rank	Country	Documents	Citations
1	United States	206	3,509
2	Netherlands	30	969
3	Australia	29	299
4	Germany	36	232
5	Indonesia	43	135

Research Question 2: Which researchers and research collaborations have had the greatest impact on the data literacy in Secondary School Mathematics literature?

An analysis was conducted to determine the researchers with the highest publications and citations on data literacy in mathematics in secondary schools. Table 2 reflects authors with a minimum of 6 publications and at least 10 citations. Out of 1,327 authors, only 5 meet the minimum requirements. Schildkamp has the most publications with the most citations and links. Jiang and Reeves have published six documents, one fewer than Poortman, but they both received fewer than 85 citations, while Poortman received 306 citations. Notably, South Africa is not among the top countries in data literacy in mathematics. This implies that more work needs to be done for South Africa to be among the top countries in data literacy in mathematics.

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Table 2. Top 5 Authors in Terms of Documents and Citations in Data Literacy (2012-2024)

Rank	Authors	Documents	Citations	Total Link Strength
1	Schildkamp, Kim	17	823	1,973
2	Poortman, Cindy L	7	306	1,670
3	Reeves, Todd, D	6	83	750
4	Shreiner, Tamara I	6	81	45
5	Jiang, Shiyan	6	22	26

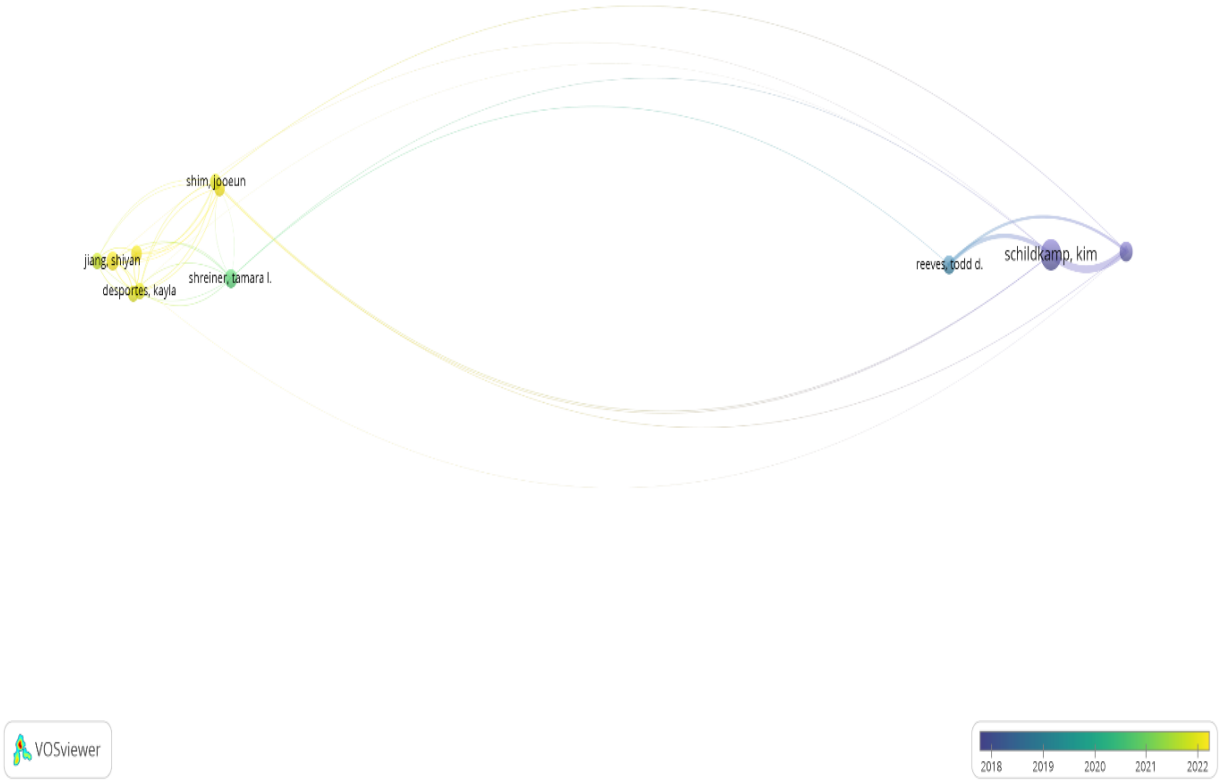

Figure 4. Temporal Analysis of Author Collaborations in Data Literacy Publications

In Figure 4, different colours represent the publishing years of the authors' work. The yellow colour indicates recent publications written by Shim, Jiang, and Desportes in 2022. The light blue colour reflects a publication released in 2020 by Shreiner. More articles were written in 2018 and 2019, reflecting strong collaboration among Schildkamp, Reeves, and Poortman.

Research Question 3: What sources have had the greatest impact in the Data Literacy in Secondary School Mathematics literature?

To address this question, a search was conducted on major sources related to data literacy publications with a minimum of 40 citations. Out of 13,987 sources, 68 met the minimum requirements. Regarding the top five sources of documents with the highest citations and their linkage strength, *Teacher College Record* has the highest citations with 426 and 12,309 links. The second highest is *Teaching and Teacher Education* with 379 citations and 9,729 links. The third is *Educational Researcher* with 311 citations and 7,986 links. The fourth is *American Educational Research Journal* with 229 citations and 7,139 links, and lastly, *Educational Administration Quarterly* with 158 citations and 7,075 links (see Table 3).

Further analysis of Figure 5 provides information on co-citation, classified into four major clusters with unique colours. Figure 5 includes 67 sources of data literacy-related papers with at least 40

citations. The four clusters of data literacy-related sources are:

- **Blue Cluster**: Composed of 7 sources. Key sources include *Review of Educational Research*, *The Elementary School Journal*, *The Reading Teacher*, and *Educational Leadership*.
- **Green Cluster**: Composed of 17 sources. Key sources include *Data-Based Decision Making*, *Studies in Educational Evaluation*, *Teaching and Teacher Education*, *Teacher College Record*, *American Educational Research*, and *Educational Research*.
- **Yellow Cluster**: Composed of 5 sources. Key sources include *Educational Management Administration*, *Phi Delta Kappan*, and *Journal of Educational Administration*.
- **Red Cluster**: Composed of 38 sources. Key sources include *Computers in Education*, *Sustainability*, *Learning and Instruction*, *Educational Psychology*, *Journal of the Learning Sciences*, *Cognition and Instruction*, *Statistics Education Research Journal*, and *Journal of Science Education*.

Six sources relate directly to mathematics education.

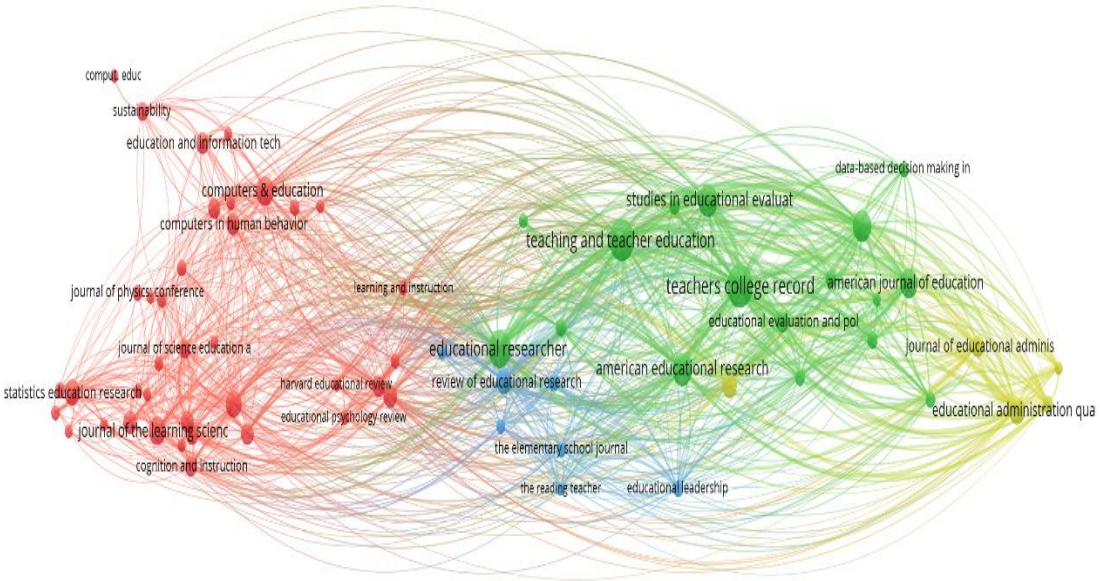

Figure 5. Co-Citation Analysis of Data Literacy Sources

Table 3. Top 5 Sources Based on Citations and Linkage Strength

Rank	Source	Citations	Links
1	Teacher College Record	426	12,309
2	Teaching and Teacher Education	379	9,729
3	Educational Researcher	311	7,986
4	American Educational Research Journal	229	7,139
5	Educational Administration Quarterly	158	7,075

Research Question 4: What are the most important topics in the Data Literacy analysis in Mathematics Literature?

A VOSviewer analysis was conducted on data literacy in mathematics using all keywords with a minimum of five occurrences. Out of 1,881 keywords related to data literacy in mathematics in secondary or

high school, 84 met the threshold. This implies that each publication included five keywords contained in the search engine. The outcome of the search is reflected in Figure 6, which contains the network of keywords generated from the database. Each node denotes a keyword, with the size of the node corresponding to the frequency with which the keyword was used.

From Figure 6, we realize that "data literacy" was the most used keyword, occurring 70 times with 70 links. Other frequently used keywords were:

- Students (occurring 61 times with 69 links)
- Data use (occurring 32 times with 17 links)
- Education (occurring 19 times with 42 links)
- Professional development (occurring 17 times with 24 links)
- Assessment (occurring 12 times with 16 links)
- Data-driven decision making (occurring 12 times with 9 links)

From Figure 6, we further note that during 2020 and 2021, researchers focused on "data literacy," "professional development," and "school improvement." However, from 2022 to 2023, the focus shifted towards "schools," "teachers," "high school," "curriculum," and "data analysis."

More research is needed in the field of education relating to the links between data literacy and mathematics in high school with the deliberate intent of leveraging data-driven decisions to better instruction and pedagogy.

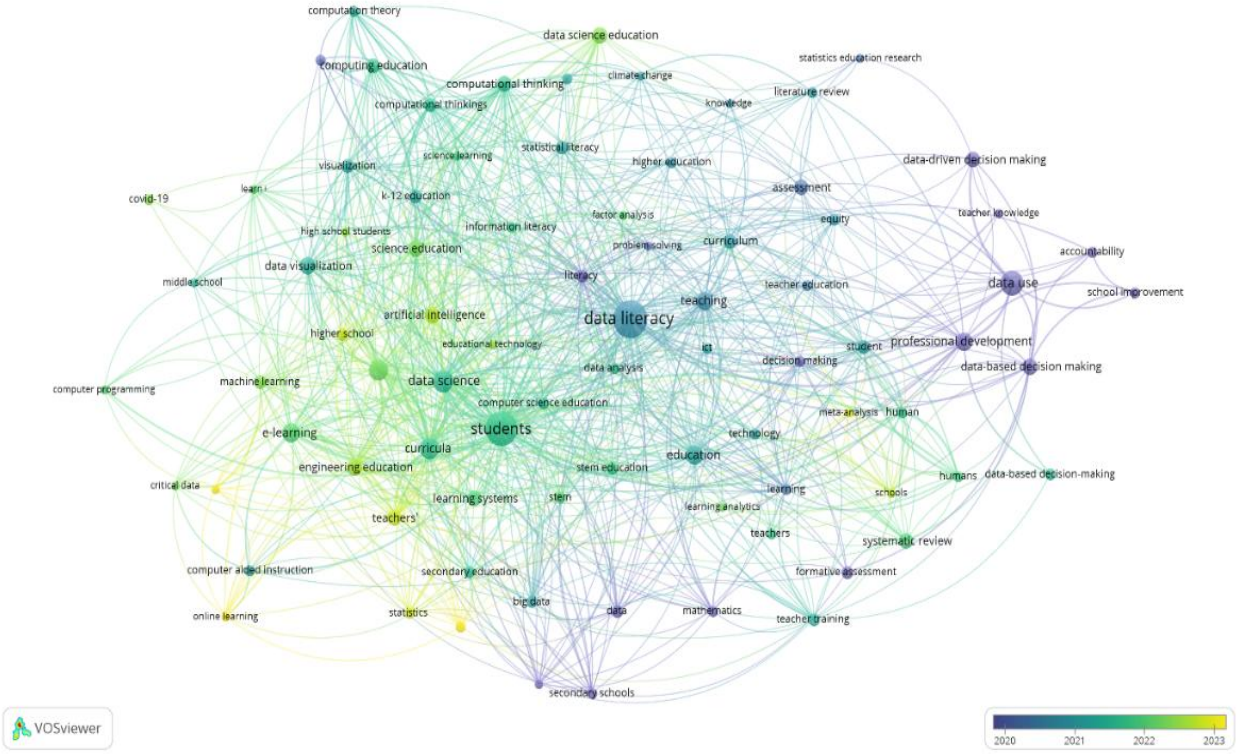

Figure 6. Mapping of Authors' Keywords based on Co-occurrence Analysis of Author's Keywords in Data Literacy between 2012 and 2024.

Discussion

The findings from this study provide a comprehensive overview of the state of data literacy in mathematics education, particularly within secondary and high school contexts. This discussion section synthesizes the key insights from the analysis and offers interpretations, implications, and suggestions for future research and practice.

Geographic Distribution of Publications

The dominance of the United States in publications and citations related to data literacy in mathematics education is significant, with 206 publications attributed to this country. This aligns with

previous studies that have highlighted the strong emphasis on data-driven decision-making in U.S. educational policies (Rožman et al., 2023). The notable contributions from Indonesia, Germany, the Netherlands, and Australia further illustrate the global interest in this field. However, the underrepresentation of South African researchers suggests a need for increased research activity and international collaboration in this region to enhance its impact on the global stage (Nawang et al., 2022).

Key Researchers and Research Collaborations

The identification of key researchers, such as Schildkamp and Kim, underscores the importance of individual contributions to the field. These researchers have produced a significant body of work that has been widely cited, indicating their influence on the development of data literacy in education (Schildkamp et al., 2019). The strong collaborative networks among these researchers suggest that impactful research in this area often involves partnerships, which can lead to more comprehensive and robust findings (Mertala, 2020). Encouraging such collaborations, especially involving underrepresented regions, could further advance the field.

Impactful Sources

The analysis of sources revealed that journals like "Teacher College Record" and "Teaching and Teacher Education" are pivotal in disseminating research on data literacy. These journals' high citation counts and linkage strengths highlight their role in shaping the discourse on data literacy in mathematics education (Hachmeister et al., 2021). The clustering of sources into distinct research communities suggests diverse approaches and perspectives within the field, which can enrich the overall understanding and application of data literacy (Atenas et al., 2023).

Key Topics and Trends

The keyword analysis indicates that "data literacy" is the most frequently used term, reflecting its central importance to the field. The prominence of keywords such as "students," "data use," "education," "professional development," and "assessment" underscores the multifaceted nature of data literacy, encompassing various aspects of educational practice and policy (Yan & Li, 2023). The shift in research focus from data literacy and professional development to more specific areas such as school improvement and curriculum development in recent years suggests an evolving understanding of the field and its applications (Prado & Marzel, 2013).

Implications for Research and Practice

The findings of this study have important implications for both research and practice in the field of data literacy in mathematics education. One key implication is the need to encourage international collaboration. The strong collaborative ties identified in the study suggest that fostering international partnerships can significantly enhance research productivity and impact. Efforts should be made to facilitate such collaborations, especially involving researchers from underrepresented regions like South Africa. Another implication is the necessity of broadening the research focus. The evolving focus of research topics indicates a need to address emerging challenges and opportunities in data literacy. Future research should explore the practical applications of data literacy in various educational contexts and its impact on teaching and learning outcomes.

Additionally, leveraging influential sources is crucial. Researchers should consider publishing in highly cited journals like "Teacher College Record" and "Teaching and Teacher Education" to increase the visibility and impact of their work. Engaging with the distinct research communities identified in the source clustering can also provide valuable perspectives and insights. Finally, the analysis highlights gaps in the literature, particularly in regions with lower research output and among certain topics that have not been extensively explored. Targeted research efforts can address these gaps and contribute to a more comprehensive understanding of data literacy in mathematics education.

Conclusion

This study provides a detailed overview of the landscape of data literacy research in secondary school mathematics education. By identifying key contributors, influential sources, and emerging trends, it offers valuable insights for researchers, educators, and policymakers. The findings underscore the importance of international collaboration, the need for a broad research focus, and the potential for leveraging influential sources to advance the field. Future research should continue to explore the practical applications of data literacy and address the identified gaps to enhance educational practices and outcomes globally.

Recommendations

This study highlights several strategic recommendations to strengthen data literacy in secondary mathematics education. First, fostering

international collaboration is crucial, particularly involving underrepresented regions such as South Africa. Research partnerships, joint publications, and exchange programmes can diversify perspectives and enhance global impact. Institutions and funding agencies should support these efforts. Second, there is a need to build educators' capacity through targeted professional development. Both pre-service and in-service programmes should focus on equipping teachers with practical skills to collect, analyse, and apply data to improve instruction, assessment, and student outcomes. Future research should expand beyond general discussions of data literacy to explore its application in curriculum development, school improvement, and technology integration. Addressing practical challenges will increase the relevance and utility of research findings. In addition, interdisciplinary collaboration among researchers, educators, and policymakers is essential to bridge the gap between theory and practice and promote data-informed decision-making in education. Finally, targeted efforts should address current research gaps, especially those relating to marginalized regions and equity issues. Establishing networks or observatories focused on data literacy can support knowledge sharing, mentorship, and alignment with global educational goals.

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