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Mapping the Terrain: A Comprehensive Review and Bibliometric Analysis of Data Literacy in Mathematics Education (2009-2024)

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Abstract: Despite receiving increased attention from researchers in mathematics education, there is still no comprehensive understanding of the current level of data literacy in the teaching and learning of mathematics. To address this gap, this study presents a review of 247 papers selected from the Scopus database between 2009 and 2024. The research aims to explore the following: (i) The overall volume, geographic distribution, and development trajectory in the literature on data literacy in mathematics. (ii) The researchers and research collaborations that have had the greatest influence on the literature on data literacy in mathematics. (iii) The sources that have had the greatest influence on the literature on data literacy in mathematics. (iv) The most important topics in the literature on data literacy in mathematics. It was discovered that the number of publications involving data literacy in mathematics increased from 2016 to 2023. Authors from the Netherlands are the most active in the literature on data literacy in mathematics. The Teacher College Record had the highest number of citations. Lastly, the most important topics addressed in the literature on data literacy in mathematics were data use, data literacy, and data-based decision-making. This study has implications not only for mathematics education researchers but also for other stakeholders in the education sector, including school principals, policymakers, and mathematics teachers.

Keywords: Data literacy, bibliometric analysis, mathematics education, data literacy, comprehensive review.

1. Introduction

Data literacy is widely recognised as a valuable skill that enhances data-driven interventions, data-use engagements, school improvement, and the teaching and learning process (Diery et al., 2020). Bruniges (2019) asserts that data literacy improves educational performance and empowers school improvement. Researchers generally agree (Wise, 2020; Mandinach & Schildkamp, 2021) that data literacy encompasses the ability to comprehend, create, evaluate, and communicate data as information, as well as critically evaluate the methods of generating and using data.

To grasp the relationship between data literacy and teaching and learning, the original work of Gummer and Mandinach (2015) provides valuable insights. They define data literacy as a teacher's capacity to transform data into actionable pedagogical knowledge. This refers to the extent to which teachers can collect and analyse data generated within the teaching and learning context to gain insights for advancing teaching and learning.

Gummer and Mandinach (2015) emphasise the importance of data utilisation as a critical skill in effective teaching and assessment techniques. Furthermore, Brown (2023) argues that data literacy is crucial in navigating the digital explosion, enabling decision-making, and fostering critical thinking.

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Ab.Wahid (2022) adds that educational reform efforts focusing on developing and nurturing 21st-century competencies have placed greater emphasis on data-driven decision-making and the teaching and learning process (Zakaria & Latif, 2021). As a result, teachers are expected to possess digital and data literacy skills to effectively utilise both available and self-generated data to enhance their teaching and learning (Nimy et al., 2023; Mandinach & Schildkamp, 2021).

However, research indicates that the substantial benefits of data use have not been consistently embraced, even in countries where data use is mandatory. Studies on teachers' data use and proficiency in data-related activities have yielded diverse findings. While a growing body of evidence supports integrating data-driven interventions into teachers' teaching and learning processes (Diery et al., 2020), numerous studies have also highlighted the obstacles and challenges teachers face when engaging with data. Michos, Schmitz, and Petko (2023) conducted research on the factors that hinder teachers from effectively utilising data in their practice. They discovered that lack of knowledge and skills were relatively minor issues but identified psychological reasons, such as feeling overwhelmed and hesitation, as well as teachers' self-efficacy and beliefs in the superiority of personal judgements and intuitions, as key barriers to data engagement. Andersen (2020) also found that data use among teachers lacked depth and tended to be superficial, characterised by reliance on a single source of data, incomplete data use processes, and limited application to specific groups of students.

Despite the existing studies on the psychological barriers and superficial data engagement among teachers, there is still a lack of comprehensive understanding in this area. Additionally, in the context of mathematics teaching, there is a dearth of research that takes a comprehensive meta-analytical approach, combining findings from different settings and historical periods. To address this gap, bibliometric analyses can be employed to map the research landscape, identify trends and networks, and discern recurring themes and patterns across studies. These analyses can also identify research gaps, directing future investigations to understudied areas. Therefore, bibliometric reviews are crucial for comprehending the usage and engagement of data among teachers and for informing targeted interventions and policy-making, particularly within the realm of mathematics education.

The aim of the study is to conduct a descriptive bibliometric analysis of research on data literacy in mathematics published between 2009 and 2024. This analysis seeks to categorise the current state of research, identify prevalent themes, trace the development trajectories of scientific inquiry, and highlight leading studies or research in the field of data literacy in mathematics education.

Bibliometric analysis utilises descriptive statistics to uncover trends and growth patterns within a body of literature, enabling a deeper understanding of knowledge production (Hallinger & Kovačević, 2019). Pritchard (1969) pioneered the use of bibliometric analysis to quantify scientific activity based on the structure and content of scientific publications. Binh et al. (2021) assert that this approach can be employed to identify trends and track the evolution of research fields over time. Several researchers (Hallinger & Nguyen, 2020; Julius et al., 2021; Pham et al., 2020) have already utilised bibliometric analyses to investigate the development of various research fields, such as social sciences, lifelong learning, sustainable development, STEM education, higher education, and mathematics education. However, the application of bibliometric analysis in mathematics education research remains relatively uncommon (Drijvers et al., 2020).

This study investigates the bibliometrics of the keyword "data literacy" as an overarching topic and explores its application in the domain of mathematics education. Scopus-indexed publications are employed to collect metadata, with the VOSViewer software utilised for visualisation purposes.

1.1 Research questions

This research is anticipated to define trends, novelties, patterns, and future research on "data literacy" in the field of teaching and learning mathematics over the last fifteen years (2009–2024). In detail, the following four research questions will be studied:

- What is the total volume, geographic distribution, and growth trajectory in the Data Literacy in mathematics literature?
- Which researchers and research collaborations have had the greatest impact on Data Literacy in mathematics literature?
- What sources have had the greatest impact on Data Literacy in mathematics literature?
- What are the most important topics in the Data Literacy in mathematics literature?

2. Methods and Materials

Pritchard (1969) introduced bibliometrics as a distinctive approach for conducting literature reviews. Since then, bibliometric analysis has been widely employed to investigate various research topics. For instance, Ersozlu and Karakus (2019) examined 537 papers indexed in Web of Science from 2000 to 2018, aiming to map the literature on mathematics anxiety and its impact on learner performance. These studies utilised diverse bibliometric methodologies, such as scientific mapping and coauthor analysis, to gain insights from their research. Building upon the aforementioned studies, the present study analyses 247 documents indexed in Scopus between 2009 and 2024 in order to address the four research questions identified earlier.

2.1. Search strategy

This study conducted an extensive literature search to identify phrases related to data literacy using various keywords and combinations. For instance, the search criteria included terms such as "data literacy" AND "mathematics" AND "primary school" OR "elementary school". The search covered publications from 2009 to 2024. Initially, 303 papers were identified through the literature search. After a rigorous screening process, which involved excluding titles that were irrelevant to the topic of inquiry, 247 papers were retained. Subsequently, all 247 papers underwent a comprehensive evaluation of their full texts. The process of finalising the prior investigations in this review is illustrated in Figure 1.

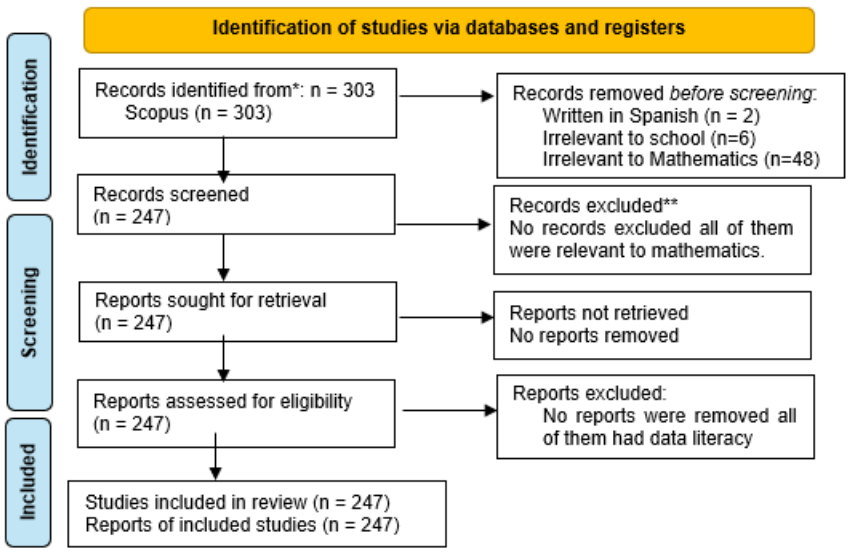

Figure 1: *Study Review Process*

2.2. Inclusion and exclusion criteria

We applied a set of inclusion and exclusion criteria to select relevant papers for our study. Only papers that met the following criteria were considered: they were published in English, peer-reviewed, and emphasised the integration of data literacy or mathematics training. Specifically, we included studies that explored topics such as data literacy, data usage, data-driven decision-making, professional development for teachers, school improvement, assessment, mathematics, and education. Consequently, articles solely focused on data literacy and mathematics in higher education were excluded as they did not align with the main objective of our paper, which is to examine the impact of data literacy on mathematics teaching and learning in primary school. Furthermore, studies that investigated data literacy outside the context of mathematics education were also excluded. Additionally, any other systematic reviews related to the keywords were disregarded. After applying these criteria, a total of 247 articles remained and were included as the final sample for analysis.

2.3. Extraction and data analysis

In this study, the methodology of bibliometric analysis is combined with bibliometric visualisation tools. Qiu et al. (2020) argue for the use of bibliometric analysis to identify current research fields and future research directions. The VOSviewer software is employed to collect, assess, and visualise bibliographic data. The authors examined and visualised the bibliographic coupling of authors, sources, nations, co-occurrences of author keywords, and institutions. According to Eck and Waltman (2017), VOSviewer is considered one of the most widely used computer applications that offers a range of visualisation techniques.

3. Presentation of Results

The subsequent section presents the results in accordance with the research questions: What is the total volume, geographic distribution, and growth trajectory of Data Literacy in mathematics literature? Which researchers and research collaborations have had the greatest impact on Data Literacy in mathematics literature? What sources have had the greatest impact on Data Literacy in mathematics literature? What are the most important topics in Data Literacy in mathematics literature? In this presentation, each question forms a theme as follows: geographic distribution and growth trajectory of Data Literacy in mathematics, researchers and research collaborations on Data Literacy in mathematics, sources with the greatest impact on Data Literacy in mathematics, and important topics in Data Literacy in mathematics.

3.1 Geographic distribution and growth trajectory of data Literacy in mathematics

In order to answer the above question, we analysed the papers published between 2009 and 2024 on data analytics, and the results are presented in Table 1 below. The results show that within this timeframe, there were no papers published on data literacy between 2010 and 2011, which is a period of 2 years. During the analysis phase, the papers' bibliographic coupling of the countries was filtered in the VOSViewer. Only the countries that had at least five publications were included in this analysis. Out of the 51 countries, 14 met the threshold. Countries in Asia and Africa did not meet the threshold. This does not necessarily mean that there are no data literacy publications in these countries; however, it indicates that they have less than five publications on data literacy or no publications at all. Nevertheless, this absence is not surprising since the increase in scholars' interest in data literacy is correlated to the advancements in artificial intelligence (Michos et al., 2023). Thus, this connection with AI seems to explain the lack of papers on data literacy in our final selection.

Figure 2: *Publication trend - 2009 - 2023.*

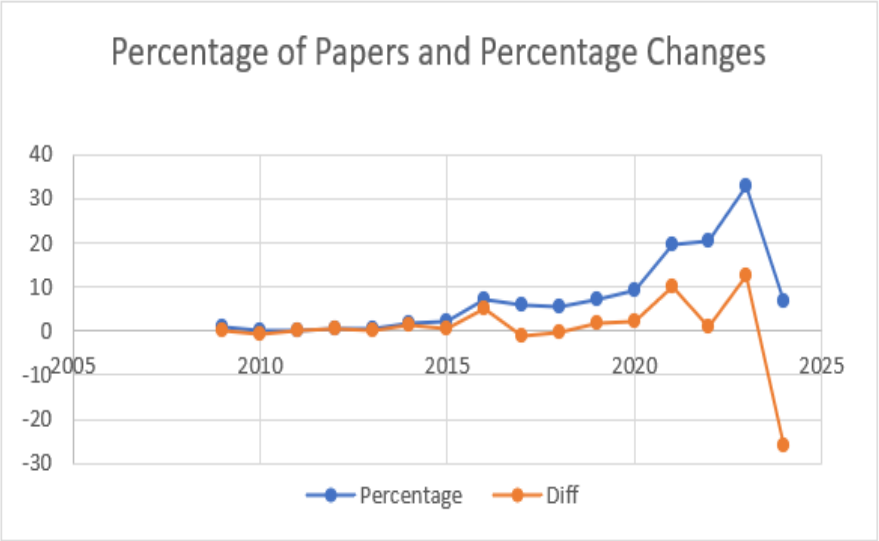

Figure 3: *Publication growth in percentage*

In contrast, for the period 2016 to 2023, we noticed a growing trend in the number of publications on data literacy, with 2023 being the highest at 81 papers. This growth is evident in a total of 200 papers published in this seven-year period on data literacy. In Figure 2, the red line, labelled "Diff," denotes the year-over-year percentage change in publications on data literacy. The results displayed in Figure 2 show that besides a steady growth in publications on data literacy, there was a noticeable sharp percentage increase of 10.12% and 12.55% in the years 2021 and 2023, respectively.

Thus, from the foregoing, we have answered part of the question, which is the volume and trend of publications on data literacy. We found that there were a total of 200 publications and steady growth, which peaked in 2023 with 81 publications, representing a 12.55% increase from 2022. To continue answering the question, we subsequently explore the geographical distribution of the publications.

Regarding the geographical distribution of data literacy-related publications, it can be perceived that countries such as Australia, the United States, the Netherlands, and Indonesia have larger circle diameters than other countries. Based on the demonstration in Figure 3, it can be perceived that the

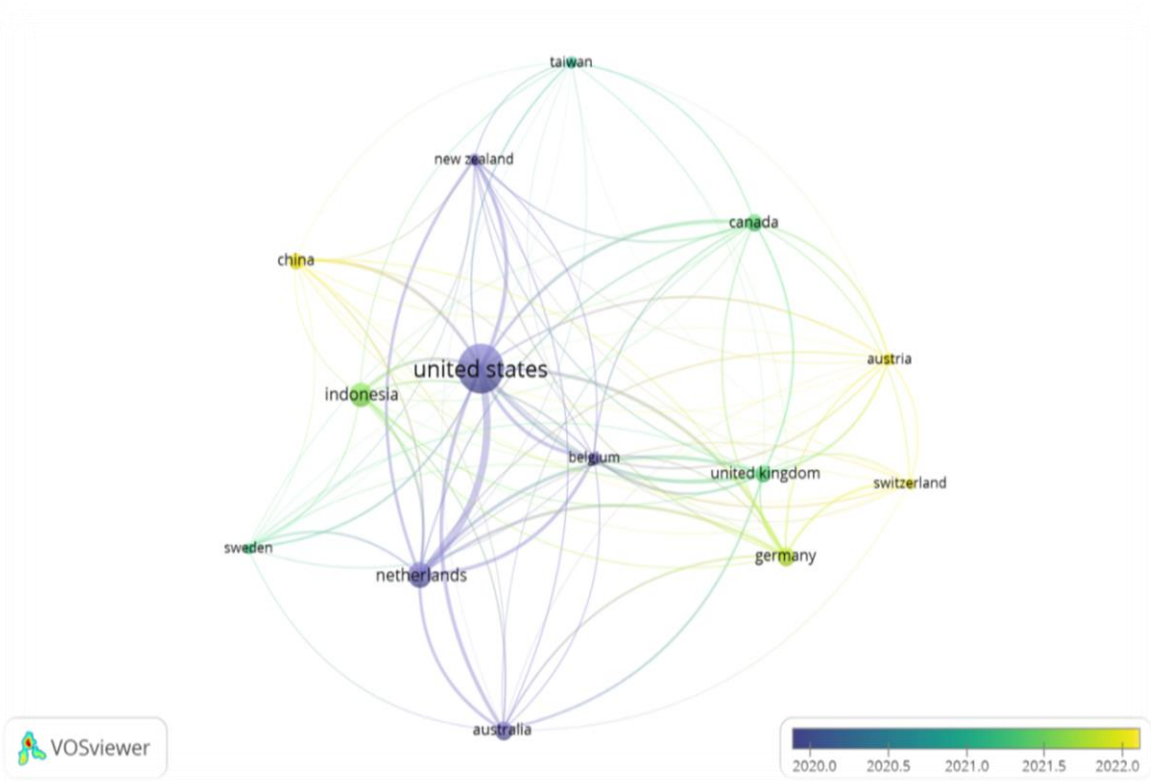

Figure 4: Bibliographic coupling of countries

The United States, the Netherlands, and New Zealand have cooperative relations with 13 countries. The most actively publishing nation in this area of data literacy is the United States, and it is interesting to observe from Figure 3 that it has also collaborated with all the countries that have published papers related to data literacy and mathematics teaching and learning. To be more detailed, researchers from the United States published 101 data literacy mathematics education-related papers, which make up 40% of the total 247 papers.

To better comprehend the collaboration among data literacy in mathematics education scholars from various nations, we utilised VOSViewer to create a scientific mapping that represented the coauthoring patterns. Every node in Figure 3 signifies a country. The size of every node indicates the amount of data literacy in mathematics education-related publications produced by writers from that nation. The line linking the two nodes shows the coauthoring activity of writers from both nations. The broader the line, the more papers were coauthored by the various nations. As illustrated in Figure 3, the three most common collaborations are US-Netherlands, Australia-Netherlands, and US-New Zealand. Specifically, 101 papers were coauthored by researchers from the US and the Netherlands, while the figure for US-New Zealand indicates 25 papers and the Australia-Netherlands 41 papers. Remarkably, South Africa has not collaborated with the most productive countries in data literacy mathematics education studies. Therefore, this data necessitates a study of data literacy in South African mathematics education.

Aside from coauthoring trends, Figure 4 depicts the most recent studies on data literacy in mathematics education from various nations. The navy or purple nodes indicate countries whose authors have examined data literacy in mathematics education up to 2020. The most prominent node in purple represents the United States. The "Persian green" node represents countries that first incorporated data literacy in mathematics studies between 2020 and 2021, with Indonesia being the clearest example.

After 2021, China is the most frequently represented country in studies on data literacy in mathematics education, indicated by the yellow nodes. It is worth noting that China has published 11 documents and has collaborated with Switzerland, Germany, and Austria after 2021. Taking a closer look at the comprehensive dataset reveals that the year 2022 stands out as a significant milestone for studies on data literacy in mathematics education in China.

3.2 Researchers and research collaborations on data literacy in mathematics

Table 1 lists the highest researchers of data literacy in mathematics education based on numerous papers and citations. Remarkably, there is a large discrepancy between the two ranks (by papers and citations), implying that writers with the most publications on data literacy in mathematics education may not have the most citations, and vice versa. For example, Reeves released 8 documents on data literacy (ranked second in quantity of publications) but received only 106 citations in total, falling short of the top five. On the contrary, Poortman obtained 152 citations but only produced four data literacy publications (ranking 5 in number of documents).

Authors from the Netherlands appear to dominate the top five data literacy authors in terms of documents. The United States and the Netherlands appear to dominate the top five data literacy writers in terms of citations. Two of the top five data literacy writers by citations are from the United States, while three are from the Netherlands, as represented in Table 2. Another intriguing result from Table 1 is that South African writers are not represented among the top researchers, either in citations or in papers. This indicates a gap in the Data Literacy in mathematics education literature in South Africa. Thus, the gap presents South Africa and other African countries with an opportunity to contribute to the scholarly debates on an emerging and critical field of data literacy. Data Literacy is increasingly becoming a key competency in the digital age, especially for informed decision-making across various sectors. In addition, the absence of the African continent suggests that the body of knowledge on data literacy may not fully address the unique challenges and opportunities present within this region.

Table 1: *Top 5 authors based on number of publications and citations in data literacy between 2009 and 2024*

Top 5 data literacy authors in terms of docume				**Top 5 data literacy authors in terms of citations**			
Rank	Author	Affiliation	Document	Rank	Author	Affiliation	Citations
1	Schildkamp, K	University of Twente, Netherlands	10	1	Schiedam, K	University Twente, Netherlands	426
2	Reeves T.	University of Georgia, USA	8	2	Datnow A	University Carlifonia, USA	317
3	Visscher, A	University of Twente, Netherlands	7	3	Visscher, A	University of Twente, Netherlands	242
4	Datnow, A	University of California, USA	5	4	Poortman, C	University of Twente, Netherlands	152

5	Poortman, C.	University of Twente Netherlands	10	5	Marsh, J	University of Southern California, US	136

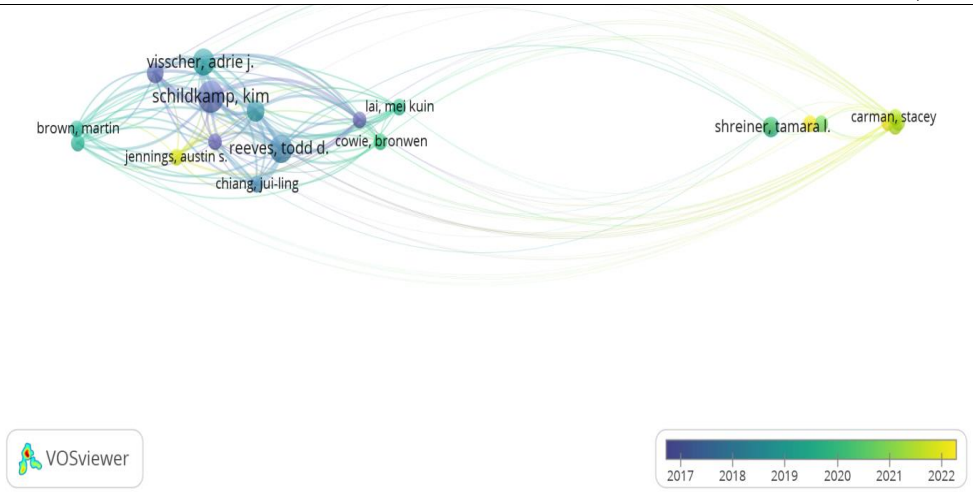

Figure 5: *Bibliographic coupling of the authors*

Similar to Table 2, the colours in Figure 4 represent the years of publication for the works of the writers. The findings reveal that Carman Stacey, Jennings Austin, and Shim Jooeun have authored the most recent papers in the field of data literacy and the teaching and learning of mathematics. These three writers have established a research collaboration and have recently coauthored numerous works on data literacy. To investigate the ways in which data literacy academics collaborate to form research groups, we employed VOSViewer to construct a scientific map that displays the co-authorship patterns among the authors. Among the 727 authors who have published documents on data literacy in education between 2009 and 2024, 21 authors have formed research groups. There are five groups consisting of at least six authors. Most of these research groups are led by authors from the United States. Table 2 below presents the top five research groups, and it is noteworthy that only one group is led by a Dutch author.

Table 2: *The top 5 major research groups/ collaborations in data literacy studies*

Head of group	**Affiliation**	**Number of coauthors**
Carman, S	Missouri Botanical Garder	8
Coulter B	Missouri Botanical Garder	8
Schildkamp K	University of Twente, Netherlands	6
Shim J	University of Pennsylvania	8
Yoon S	University of Pennsylvania	6

3.3 Sources with the greatest impact on data literacy in mathematics

Table 3 displays the major sources of data literacy research, based on the quantity of data literacy-related papers and their citations. Regarding the number of documents, the Teaching and Teacher Education journal is dominant, with 13 documents published. Teachers College Record journal has the most citations (314). It can also be observed that the top journal does not necessarily have the most citations. Unlike the top writers, our findings on top sources show that the two top lists have more substantial common sources.

Table 3: *The top 5 major research papers in terms of the number of documents and citations in data literacy studies*

Top 5 data literacy sources in terms of documents			**Top 5 data literacy sources in terms of citations**		
Source	Source type	Documents	Author	Affiliation	Citations
Schildkamp, K.	University of Twente, Netherlands	10	Schiedkamp, k	University of Twente, Nerthelands	426
Reeves T.	University of Georgia, USA	8	Datnow A	University of California, USA	317
Visscher, A	University of Twente, Netherlands	7	Visscher, A	University of Twente, Netherlands	242
Datnow, A	University of California, USA	5	Poortman, C	University of Twente, Netherlands	152
Poortman, C.	University of Twente, Netherlands	10	Marsh, J	University of Southern California, USA	136

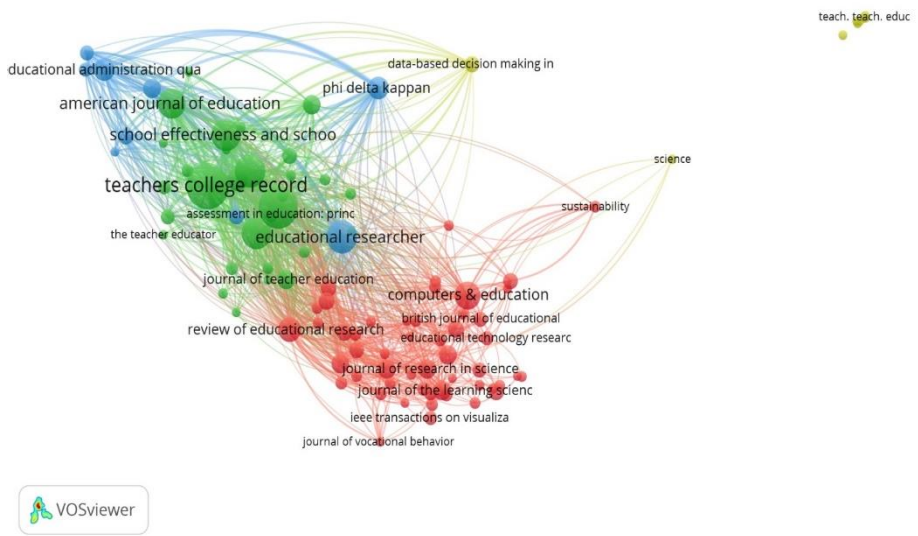

Figure 6: *Sources by citation*

The descriptive analysis given in Table 3 does not fully capture the level of effect of linked sources. To get a more complete picture of influential sources in data literacy research, we used Pham's (Pham et al., 2021) recommendation to do a co-citation analysis. Figure 5 depicts our co-citation study of 99 sources of data literacy-related papers with at least 20 co-citations. This figure can lead to four groups of data literacy sources: 1. the red cluster, which is composed of 51 sources. The key sources of this cluster include Computer and Education, Review of Educational Research, and Journal of Learning Science. 2. the green cluster, which is composed of 30 sources. The key sources of this cluster include

the American Educational Research Journal, Cogent Education, and British Educational Research. 3. The blue cluster, which is composed of 9 sources. The key sources of this cluster include Educational Administration Quarterly, Educational Leadership, Educational Policy, and Educational Researcher. 4. The yellow cluster, which is composed of 8 sources. The key sources of this cluster include data-based decision-making in education, including challenges and opportunities, educational research, and the International Research Journal in Education and Science.

It is worth noting that the majority of these 99 data literacy-related papers appear to be educationally useful. However, there are few sources that explicitly relate to mathematics education, such as Educational Studies in Mathematics, International Journal of Science and Mathematics Education.

Specifically, there are eight sources that relate directly to mathematical education, including the International Journal of Mathematical Education in Science and Technology and the Journal for Research in Mathematics. The findings indicate a gap in data literacy and mathematics education

3.4 Important topics in data literacy in mathematics

To address the research question at hand, a co-keyword analysis was conducted using VOSViewer. Each text was assigned a set of keywords, typically around five per paper. Figure 6 presents a network diagram illustrating the co-occurrence of these keywords within our database. Each node within the diagram represents a specific keyword, with the size of the node denoting the frequency of its appearance in the selected papers on data literacy. The hue of each node indicates the recency of its usage. The diagram presented in Figure 6 reveals that, in addition to the term "data literacy"

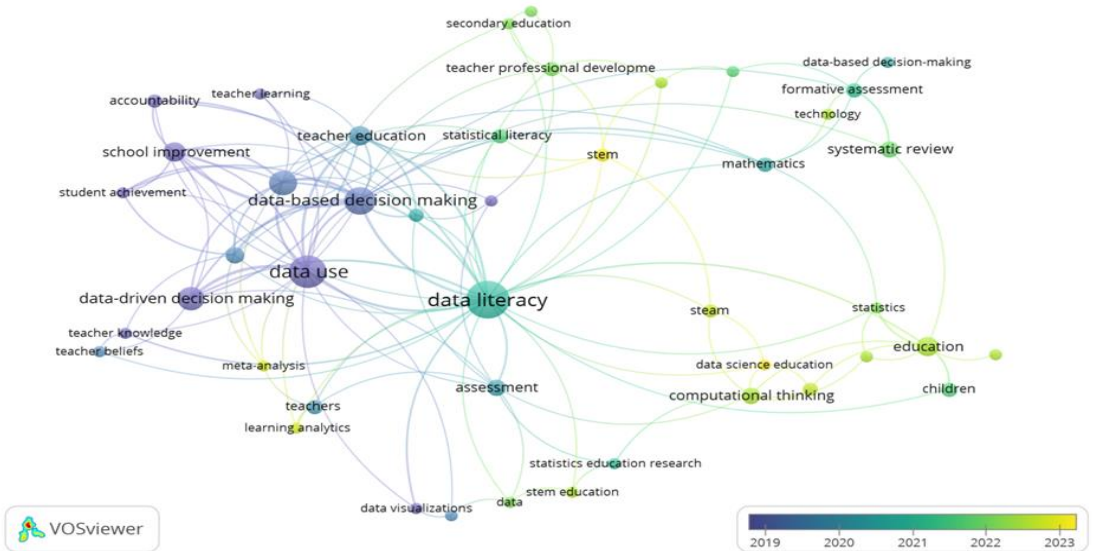

Figure 7: *Mapping of author's keywords based on co-occurrence analysis of author's keywords.*

(appearing 33 times), the most frequently utilised keywords include "data usage" (25 times), "data-driven decision making" (18 times), "students" (16 times), and "professional development" (15 times).

Moreover, it would be beneficial to assess the most significant keywords that have recently emerged in this field. The latest research in this literature encompasses topics such as data literacy, education, students, e-learning, learning systems, and teacher development. Furthermore, the connection between data literacy and mathematics underscores an emerging trend toward the utilisation of data-driven approaches in the teaching and learning of mathematics.

4. Discussion of Findings

Four features have been explored, which correspond to four research questions: (i) total volume, growth trajectory, and regional distribution; (ii) authors and research groups; (iii) sources (journal, book, conference); and (iv) the most relevant themes. Data literacy in mathematics teaching and learning research has gained momentum both statistically and geographically in many nations throughout the world, with articles from the Netherlands playing an important role, particularly after 2017. As can be seen, the top most referenced author list is dominated by a Dutch author who has collaborated with writers from the United States on data literacy projects. The coauthor mapping clearly illustrates the historical cross-country collaboration in data literacy studies. Despite the outnumbered international networks of Dutch scholars, the United States of America proves to be an important hub for global collaboration for data literacy research. Furthermore, Australia and Indonesia have remarkably contributed to the data literacy publications and in collaborating with other countries.

The findings also reveal that the journal with the most data literacy publications is The Teaching and Teacher Education. Notably, this journal, with 13 articles, specialises in publishing works primarily concerned with teachers, teaching, and/or teacher education. The second most prolific data literacy journal is Studies in Educational Evaluation, with 11 articles. Regarding the research topics, another significant keyword from the selected data literacy articles is "data use." This seems to point to the increasing attention to using data to inform decisions in education, as well as the authors' interest in applying and evaluating the effectiveness of data literacy in the teaching and learning of mathematics. Co-occurrence analysis of the authors' keywords shows "computer and education," "review of educational research," and "journal of learning science." It can be seen that despite the influence of data literacy in mathematics education, the keyword "computer and education" studies embrace data literacy as an underlying component of digital literacy due to the usage of technology to drive better outcomes.

5. Conclusions and Recommendations

This study summarises and assesses advancements, topics, and collaborations in the field of data literacy. The increasing number of data literacy-related publications, as well as their growth over time, indicate that education academics have been paying more attention to data literacy in recent years, particularly after 2016. This reflects the community's growing need for mathematicians and math teachers to modernise mathematics education and make it more applicable to real-world situations. Additionally, our findings on the geographical distribution of data literacy-related papers confirm that the United States and the Netherlands have been pioneers in adopting data literacy. Consequently, 727 authors from 51 different countries have conducted research on data literacy. The Netherlands has the highest number of publications and the most data literacy-related publications. The articles on data literacy can be traced back to four main sources, with the majority of them published in reputable journals in the field of educational research. Design-based research and the integration of information technology in education, based on data literacy theory, continue to be popular research approaches. This demonstrates that data literacy is still being developed and implemented worldwide as part of the Fourth Industrial Revolution.

The trend of researching data literacy in education has expanded globally, with an increasing number of researchers and a wider geographical scope. Numerous publications originate from various countries across Europe, America, and Asia, reflecting significant cultural differences and the progress of national education systems. As a result, this study has significant implications for stakeholders such as data literacy researchers, math educators, school administrators, and educational policymakers in multiple countries around the world.

Furthermore, the co-authorship patterns among academics from different nations highlight the development of collaborative research in data literacy over the years. Policymakers in mathematics education can use this information to shape strategies and policies in their respective countries. Our findings on top authors and research groups can also guide new and junior researchers in data literacy studies by identifying experienced individuals from whom to learn. Policymakers can utilise these findings to consult with the relevant experts when formulating policies.

Lastly, our findings regarding the research gaps and the identification of four major clusters of references in data literacy offer a foundation for future research in this area. For instance, there is a need for further studies on using data literacy to teach mathematics in primary schools.

6. Declarations

Authors contributions: Conceptualisation (N.M.B. & M.M.); Literature review (N.M.B.); methodology (N.M.B. & M.M.); software (N.M.B.); validation (M.M.); formal analysis (N.M.B. & M.M.); investigation (N.M.B.); data curation (N.M.B.) drafting and preparation (N.M.B. & M.M.); review and editing (M.M.); supervision (M.M.); project administration (N.M.B.); funding acquisition (N/A). All authors have read and approved the published version of the article.

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Conflicts of Interest: The authors declare no conflict of interest.

Data availability: The study sourced information from publicly accessible literature without creating new datasets. For more information, please consult the references provided in the article.

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