Bibliometric visualisation of student knowledge and skills in key literacy domains

Williams E. Nwagwu[1,2][0000−0002−5225−2934]

[1] Department of Data and Information Science, University of Ibadan, 6 Benue Rd., Ibadan, 200132, Nigeria
[2] Department of Information Science, University of South Africa, Muckleneuk Campus, Preller Str., Muckleneuk Ridge, Pretoria, 0002, South Africa
willieezi@yahoo.com

Abstract. This study utilised bibliometric visualisation of keywords used to represent documents on reading literacy, scientific literacy, and mathematical literacy indexed in the Scopus database to analyse the volume and growth of the literature. The study adopted a bibliometric research design, an approach that is also quantitative. Data was collected from Scopus, and analysis was based on Scopus' built analytical facility while mapping was carried out using VOSViewer. Reading literacy is the youngest of the three literacies, with early references dating back to 1607. However, research on reading literacy began to gain momentum in 2002. Mathematical literacy is the oldest, but significant growth occurred around 2003, while scientific literacy dates back to 1963. The trend in publications shows the highest growth for reading literacy and the lowest for mathematical literacy. Analysing document types revealed that scientific literacy had the largest quantity of documents, while reading literacy had a higher proportion of articles compared to the other two literacies. The study provides valuable insights into the historical development and current trends within these literacy domains, shedding light on their changing dynamics and challenges.

Keywords: measuring student knowledge and skills · bibliometric visualisation · reading literacy · mathematical literacy · scientific literacy

1 Introduction

Literacy is generally defined as the ability to read, write, comprehend, and effectively use written language [2]. According to the OECD [28], literacy encompasses these basic skills. At the same time, UNESCO expands the definition to include the ability to identify, understand, interpret, create, communicate, and compute using printed and written materials associated with varying contexts [12]. Literacy is a fundamental skill that enables individuals to access information and knowledge that can improve their lives, and it allows them to participate actively in society and the economy. There are various forms of literacy, each essential in different contexts. Basic literacy involves reading and writing simple sentences, while functional literacy refers to using these skills in everyday life.

Advanced literacy goes further, enabling individuals to read and write complex sentences and texts and engage in critical thinking and analysis. In recent years, the concept of literacy has broadened to include scientific literacy, which is the ability to understand and use scientific information, and digital literacy, which involves effectively using digital technologies [28].

Globally, literacy is a critical skill, but there is a stark contrast between literacy rates in developing and developed countries. In many developing regions, children and adults lack access to basic quality education and literacy programs, which hinders their ability to participate fully in society. This disparity underscores the importance of global development programs like the United Nations Sustainable Development Goals, which aim to achieve universal literacy and education for all by 2030. Efforts to improve literacy rates are crucial to ensuring that all individuals have the opportunity to develop the necessary skills for personal and societal success. Educational systems around the world are constantly evolving to observe better and address students' learning challenges, reflecting the growing interest in and importance of literacy [33].

As society progresses, there is an ever-increasing need for new knowledge and capacity. Recognising this, the Organisation for Economic Cooperation and Development identified three key literacy domains in 1999: reading literacy (RL), mathematical literacy (ML), and scientific literacy (SL). These domains are critical at all levels of human existence and correspond to school subjects, forming a dynamic model of lifelong learning. They enable learners to continuously acquire new knowledge and skills necessary for adapting to changing circumstances. These literacy domains also foster successful learning by preparing students to organise and regulate their learning, learn independently and in groups, and overcome learning difficulties. Hence, literacy is not just about reading and writing; it is about equipping individuals with the tools they need to navigate and contribute to an ever-changing world. Whether through understanding complex texts, utilising digital tools, or grasping scientific concepts, literacy forms the foundation of lifelong learning and development [19, 27].

Also, reading literacy goes beyond merely decoding words; it involves comprehension, interpretation, and the capacity to evaluate information critically. It equips individuals with the skills to access, analyse, and apply knowledge from various sources, making it an essential skill in an information-rich society. Mathematics is often described as the universal language of science and technology. Mathematical literacy extends beyond mastering mathematical concepts and calculations; it encompasses problem-solving, logical reasoning, and the ability to apply mathematical principles in practical contexts. Mathematical literacy is fundamental for participation in the modern workforce and for addressing real-world challenges [28].

Scientific literacy, in turn, empowers individuals to engage with the increasingly complex and interconnected world of science and technology. It involves not only knowledge of scientific facts but also an understanding of the scientific method, critical thinking, and the ability to make informed decisions based on scientific evidence. Scientific literacy is crucial for addressing global issues, from climate change to public health, and for participating in democratic decision-making processes [25].

1.1 Statement of the problem

In recent years, the global volume of research on the three core literacies – mathematical literacy, scientific literacy, and reading literacy – has seen substantial growth. Studies conducted across various regions and cultures underscore the significance of these literacies for personal and societal well-being. Proficiency in mathematics often aligns with a higher level of scientific literacy, as mathematics provides essential tools and language for understanding scientific concepts. Similarly, strong reading skills are linked to better literacy in science and mathematics, given that comprehension of written texts relies on reading. The OECD's PISA program has played a pivotal role by developing standardised frameworks and assessments that enable international comparisons of literacy skills. This global perspective has influenced educational policies and practices worldwide, as governments and institutions often use PISA results as benchmarks for evaluating their education systems. Additionally, interdisciplinary collaboration among scholars from fields like education, psychology, and sociology has expanded our understanding of literacy beyond traditional reading and writing skills [26].

The OECD's emphasis on these literacies has far-reaching implications. It promotes a global outlook in literacy scholarship, fostering cross-country analyses that enhance our understanding of literacy trends and best practices. Moreover, the development of standardised assessments has spurred advancements in measurement methodologies and assessment techniques. This, in turn, has informed evidence-based interventions and educational programs aimed at improving these key literacies. Beyond education, the impact of these literacies extends to social and economic realms, influencing individuals' life outcomes, employment opportunities, and social engagement. In essence, research and focus on these core literacies contribute to a holistic approach to literacy that transcends mere academic skills and reaches into the fabric of society and policy-making [25].

Regarding mathematical literacy, several studies have visualised research in the area. Chen et al. [3] mapped author collaboration using big data to determine trends in publications on mathematical literacy research. They identified scholars, research institutions, countries, and regions with the most influence on research in the area and how they collaborate. They also identified research hotspots and determined the evolution trend of research in the area. Their data source was the Web of Science Core databases. Additionally, Ahyan et al. [1] examined the bibliometrics of mathematical literacy in Indonesia, visualising authors' networks and co-word mapping based on data collected from the Scopus database covering the period from 2010 to 2020. Indonesia emerged as a top country in mathematical literacy research.

As the importance of literacy grows, so too has the body of research dedicated to understanding and enhancing it. Despite this reality, Nguyen et al. [22]

have suggested that attention to the subject can be considered insufficient. Evidence from the literature shows that there is some attention to the bibliometric visualisation of research in the three areas of literacy of interest in this study, but they are all standalone studies. There is a need to examine the volume and growth of the literature on the three key types of literacy: reading literacy, scientific literacy, and mathematical literacy, over specific time periods. It is also necessary to understand the development and trends in research related to these literacies, including when they began to gain prominence, the types of documents published in these areas, and the keywords used to represent the literature in each of these fields. Additionally, it is important to understand the prominence of different document types within each category and provide insights into the composition of literacy-related materials.

1.2 Purpose of the study

This study was designed to examine the structure of the literature on the three key literacies – reading literacy, scientific literacy, and mathematical literacy – up until December 2022. Specifically, the study aims to:

1) analysed the annual volume of documents on reading literacy, scientific literacy and mathematical literacy,
2) examined the research on reading literacy, scientific literacy, and mathematical literacy by document type, and,
3) analysed the research hotspots and evolution analysis by mapping the keywords.

2 Methodology

This study adopted a bibliometric research design. Bibliometrics refers to a set of methods used to analyse academic literature quantitatively [6, p. 417]. The study mapped and visualised the keywords associated with the three literacies – reading literacy (RL: 1974-2022), scientific literacy (SL: 1963-2022), and mathematical literacy (ML: 1961-2022). Data was collected from Scopus, the world's largest abstract and citation database of scientific literature [30]. Scopus boasts the highest number of journals, conference proceedings, and other sources across all fields, offering a broader and more diverse focus compared to the Web of Science. Additionally, Scopus provides a broader geographical distribution than the Web of Science, which, despite being an advantage, can also be seen as a constraint of the database [35].

The three key literacies identified by the OECD are inherently interdisciplinary, allowing researchers to explore how these literacies have evolved and grown from various perspectives. Scopus offers bibliometric data, such as publication trends, author affiliations, and collaboration networks. Researchers can utilise this information to examine the growth of research in literacy education, identify key research institutions, and track international collaborations in this field. The historical data in Scopus, dating back several decades, enables researchers to trace the development of literacy education and policies over time and understand how societal changes have influenced the emphasis on these literacies. Scopus also allows for a global perspective on literacy research, which is crucial for understanding how different countries have approached literacy education and the impact of international assessments like PISA on literacy policies. Moreover, Scopus provides data visualisation tools that help researchers create charts, graphs, and maps to illustrate trends and patterns in literacy research, enhancing the understanding of the evolution and growth of literacy research.

While Scopus is a valuable database for academic research, it has some constraints when studying OECD's literacies or any other topic. Scopus may not cover all academic journals, particularly those from smaller publishers or non-English language journals, possibly leading to a bias towards research published in well-known journals or journals in English. Additionally, although Scopus covers a wide range of academic disciplines, it may not provide in-depth coverage of very specialised or niche topics [30]. Therefore, some literacies or subtopics within literacies may have limited coverage in Scopus. Despite these limitations, Scopus remains the most efficient database for achieving broader coverage of literature. Different terms are used to express reading literacy, scientific literacy, and mathematical literacy in the literature [38]. For example, terms like reading proficiency, effective reading, and reading comprehension are associated with reading literacy but only address aspects of the subject. This is also the case with SL and ML. Therefore, we adhered to the terminologies in the OECD framework, using "reading literacy", "scientific literacy", and "mathematical literacy" as independent search terms in the title, abstract, and keyword fields in Scopus on January 18, 2023. The scope of the search was limited to the period up to December 31, 2022, allowing the start period to be determined by the index since the concepts have different histories.

The annual growth of publications was presented as the number of documents retrieved each year (figure 1), taken as an indicator of the amount of attention researchers gave to the subject. The inbuilt analytical facility in Scopus was used to analyse document types, while the annual growth data was analysed using Microsoft Excel. We used VOSViewer, "... a software tool for creating maps based on network data and for visualising and exploring these maps" [34, p. 3], to perform the visualisation and mapping. VOSViewer permits three types of mapping: network data, bibliographic data, and text data. Our dataset was a bibliographic data set, and analysis was based on the co-occurrence of keywords. Fractional counting was the selected counting method, and "all keywords" was chosen as the unit of analysis, meaning both author-selected and indexer-selected keywords were combined. In presenting the results, the labels, clusters, total link strength (TLS), and the number of occurrences of a keyword were emphasised. Nwagwu and Williams [24] have explained the meaning of these terminologies. The labels in the tables were ranked according to their occurrences or frequency of occurrences, a measure of their popularity. Table 1 provides a summary of key indices in the retrieved data.

Table 1. Summary of key issues.

Literacy	Number of documents	Number of keywords	Keyword analysis threshold	Number of threshold keywords	R^2	Number of clusters	Start year
RL	877	2891	5	132	0.7124	8	1974
SL	2000	6249	7	237	0.6254	7	1963
ML	574	1917	5	83	0.4830	9	1961

Table 1 shows the number of documents related to reading literacy (RL), mathematical literacy (ML), and scientific literacy (SL) used in the analysis. The total number of documents retrieved for RL and ML were 877 and 574, respectively, and these were the exact numbers used in the analysis. However, for SL, while 2,851 documents were initially retrieved, only 2,000 were used in the analysis to align with Scopus's scope. This disparity is also reflected in the number of keywords, with SL producing significantly more than ML and RL – more than thrice for ML and more than twice for RL. To manage this disparity and create a more interpretable map, the keyword analysis thresholds were adjusted. For RL and ML, the number of keywords analysed matched the numbers yielded from Scopus. In contrast, for SL, the keyword threshold was increased to seven to reduce the number of keywords and achieve a more manageable and interpretable map.

3 Findings

3.1 Annual volume of documents on reading literacy, scientific literacy and mathematical literacy

Reading literacy (1974-2022). Figure 1 illustrates the growth of documents in reading literacy from 1974 to 2022. Apart from a single paper published in 1974, there was no attention to the subject in the literature until 1984. Subsequent years saw minimal activity, with two papers in 1986 and one in 1990. In 1993 and 2001, there were eight and seven papers, respectively. Although documents on the subject began to appear consistently from 1991 onwards, 2003 marks the year when research attention in this area indeed took off. Over the 48 years, a total of 793 papers were published, averaging about 17 papers per year. The pioneering paper that addressed reading literacy in 1974 was D.S. Leeds from the Department of Communication Sciences at Kean College, United States, who authored the first paper on reading literacy titled "Sociology of reading: Literacy and language", published in Reading World in 1974 [17]. This paper cited only once by Karatza [15] in 2020, reported that Smith [31] had dated reading instruction to 1607. The second document, published in 1984 by Roit and Pfohl [29], examined how informed parents were about the readability of P.L. 94–142 Parent Materials used in the United States to guide parents in getting involved in the education of their children [29]. Using MS Excel to analyse the trend, we plotted the growth of documents and displayed the slope equation and R-Square

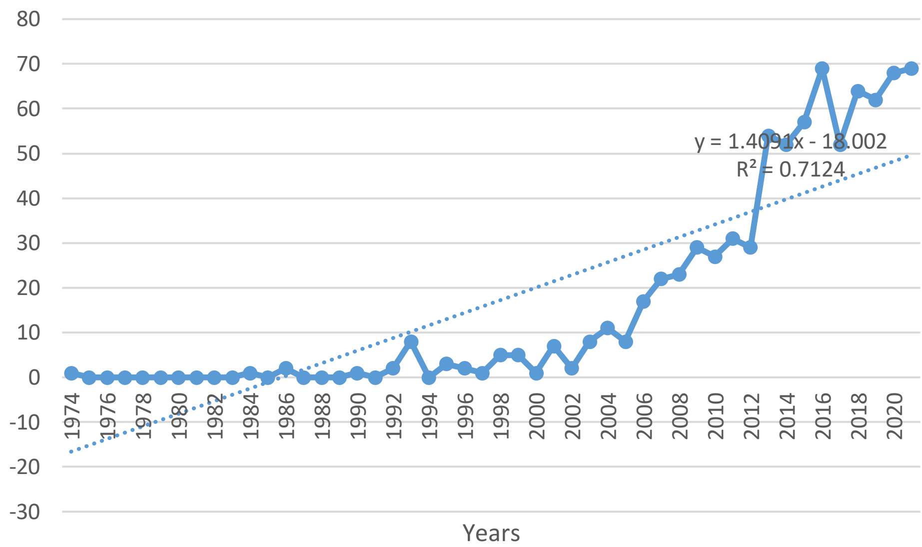

Fig. 1. Annual quantity of documents on reading literacy (1974-2022).

value, obtaining $Y = 4091X - 18.002$ and $R^2 = 0.7124$. This measure of best fit suggests that research on reading literacy will continue to grow.

Scientific literacy (1963-2022). Figure 2 illustrates the growth of documents on scientific literacy from 1963 to 2022. Between 1963 and 2002, there is consistent annual research on the subject, except for the years 1965, 1967, 1969, 1975-1976, and 1980. Notably, only a single research document was produced annually during 1963-1971. The first year to record two documents was 1972. Until 1990, research attention remained sparse, with the highest output being 11 documents in both 1989 and 1990. Since 1991, the number of research publications has consistently exceeded single digits. On average, 47 documents were published per year. Specifically, the average was 2.21 documents per year during the single-digit document production period (1963-1990) and 87 documents per year during the period from 1991 to 2022.

According to Scopus indexing, the first document to mention scientific literacy was written in 1963, titled "Scientific literacy begins in the elementary school", which also referenced mathematical literacy [36].

Mathematical literacy (1961-2022). Figure 3 shows the growth of documents on mathematical literacy since 1961. The average number of papers per year during the single-digit entry period (1961-2006) is 0.9, while the average for the double-digit period (2007-2022) is 63. We analysed the trend using the slope and displayed the equation and the R-squared value as follows:

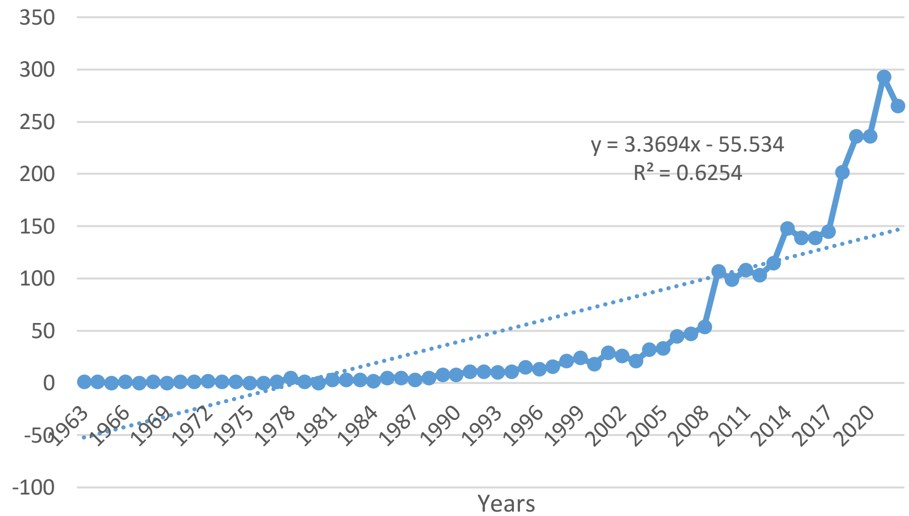

Fig. 2. Annual quantity of documents on scientific literacy (1963-2022).

$Y = 7025X - 12.87$; and $R^2 = 0.482$. This measure of best fit suggests that research on the subject will continue to grow.

By Scopus indexation, the first document on mathematical literacy was "On the Mathematical Literacy of Medical Students" by Hopkins and Berry [10]. The second document in Scopus is authored by Gaskell [9]. In this article, Gaskell [9]

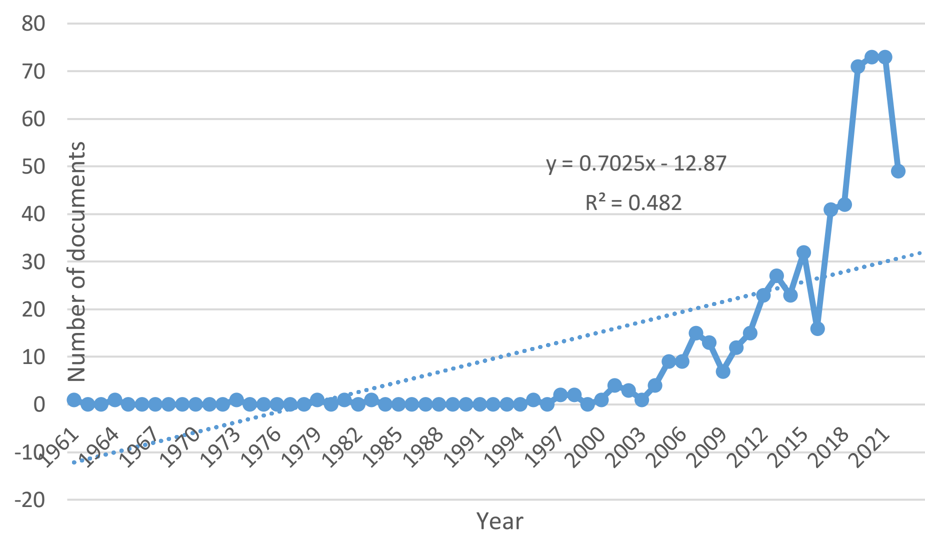

Fig. 3. Annual quantity of documents on Mathematical Literacy.

argues that mathematical literacy is becoming increasingly important in modern society and will continue to be so in the future. He defines mathematical literacy as the ability to use basic mathematical concepts and tools in everyday life, as well as the ability to reason logically and quantitatively. Gaskell notes that as technology advances and becomes more integrated into daily life, mathematical literacy will become even more crucial.

3.2 Research on reading literacy, scientific literacy, and mathematical literacy by document type

Table 2 shows the number of documents on scientific literacy, mathematical literacy, and reading literacy during their respective periods in the study. Out of a total of 877 documents on reading literacy, 689 (78.56%) were articles, while 69 (7.87%) were conference papers. Only 48 (5.47%) were book chapters, 45 (5.13%) were reviews, and 12 (1.37%) were books. From conference reviews to errata, the numbers were either fractional or zero.

Table 2. Reading literacy, scientific literacy and mathematical literacy by document type.

Document type	**Reading literacy**		**Scientific literacy**		**Mathematical literacy**	
	Quantity	%	Quantity	%	Quantity	%
Article	689	78.56	1857	65.14	296	51.57
Conference paper	69	7.87	483	16.94	187	32.58
Book chapter	48	5.47	241	8.45	61	10.63
Review	45	5.13	142	4.98	8	1.39
Book	12	1.37	36	1.26	11	1.92
Conference review	6	0.68	16	0.56	8	1.39
Editorial	5	0.57	23	0.81	2	0.35
Note	0	0	17	0.60	1	0.17
Letter	0	0	12	0.42	0	0
Short survey	0	0	5	0.18	0	0
Erratum	2	0.23	2	0.07	0	0
Total	877	100	2834	65.13	574	100

Scientific literacy has entries in all the document type categories in Scopus, with 1857 (65.14%) articles and 483 (16.94%) conference papers. Additionally, there were 241 (8.45%) book chapters, 142 (4.98%) reviews, and 36 (1.26%) conference reviews. Mathematical literacy has the lowest number of documents, totalling 574, with 296 (51.57%) articles, 187 (32.58%) conference papers, and 61 (10.63%) book chapters. There were zero documents for notes, letters, and short surveys for both reading literacy and mathematical literacy and additional zero documents for errata in the case of mathematical literacy.

3.3 Research hotspots and evolution analysis

Visualisation and mapping of all co-occurrence of keywords on mathematical literacy, 1961-2022. Table 3 and figure 4 depict the keywords used to represent research on mathematical literacy. Overall, the diversity of keywords reflects the complex and multifaceted nature of mathematical literacy, encompassing various issues and factors. The most frequently appearing term, "mathematical literacy", underscores the significant focus on fundamental mathematical concepts. Additionally, terms like "students", "teaching", and "mathematics education" highlight the critical role of pedagogy and learning processes in ML. The presence of keywords such as "PISA" and "assessment" indicates that measuring and evaluating mathematical literacy is also an important consideration. Other terms, such as "curricula", "learning systems", and "problem-based learning", suggest that the design and structure of educational programs can also play a role in developing mathematical literacy. Finally, terms such as "engineering education" and "physics" suggest that mathematical literacy may be closely connected to other scientific and technical fields.

The keywords suggest that mathematical literacy is a complex and multifaceted concept that involves many different factors, including both the content of mathematics education and the way in which it is delivered and assessed.

Cluster analysis of the keywords on mathematical literacy

ML Cluster 1: *Mathematical education and literacy*

Cluster 1 pertains to the field of mathematics education, specifically focusing on the development of mathematical literacy skills and the utilisation of mathemat-

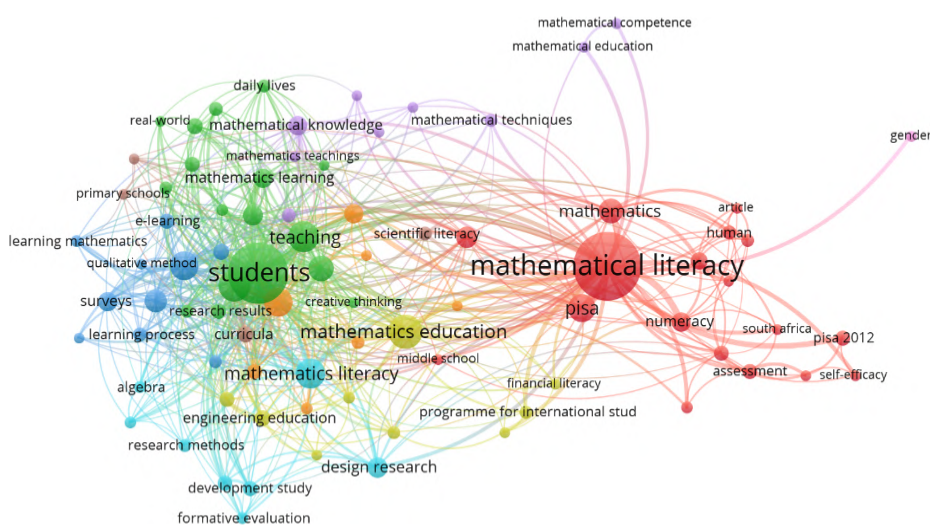

Fig. 4. Visualisation map of all keywords in mathematical literacy.

Table 3. Top 30 keywords in mathematical literacy.

№	Label	Cluster	Links	TLS	Frequency
1	Mathematical literacy	1	55	110	181
2	Students	2	74	138	143
3	Mathematics education	4	54	41	45
4	Physics	2	48	40	40
5	Teaching	2	47	38	38
6	Mathematics literacy	6	47	33	36
8	Junior high schools	7	44	33	33
7	Education computing	3	45	33	33
9	Pisa	1	17	21	31
10	Problem solving	2	40	25	25
11	Mathematics	1	29	22	23
12	Learning systems	3	30	19	20
13	Education	1	33	16	18
14	Mathematical problems	2	31	17	17
15	Design research	6	22	13	16
17	Mathematics teacher	7	27	15	15
19	Surveys	3	29	15	15
16	Mathematics learning	2	32	15	15
18	Numeracy	1	11	15	15
20	Mathematical knowledge	5	28	12	14
21	Literacy	1	15	12	12
22	Curricula	8	25	11	11
23	Engineering education	4	21	11	11
25	Problem based learning	3	24	10	10
24	Mathematical concepts	2	20	10	10
28	Development study	6	16	9	9
29	e-Learning	3	24	9	9
30	Elementary schools	2	21	9	9
26	Assessment	1	15	8	9
27	Curriculum	1	15	8	9

ical modelling within the curriculum (table 4). Mathematical literacy involves the application of mathematical concepts and reasoning to address real-world situations. In contrast, mathematical modelling entails using mathematical tools to describe, analyse, and predict complex systems or phenomena [38]. The components within this cluster illustrate that diverse factors, including curriculum design, teaching methodologies, and assessment strategies, influence the advancement of mathematical literacy.

Mathematical modelling has significant applications in diverse fields such as science, engineering, and economics. Integrating mathematical modelling into the mathematics curriculum can enhance students' development of critical thinking, problem-solving skills, and decision-making capacities [8, 14, 18].

Table 4. Cluster analysis of mathematical literacy keywords.

Clusters	**Items**	**Description**
Cluster 1	article, assessment, curriculum, education, literacy, mathematical literacy, mathematical modelling, mathematics, mathematical modelling, etc.: **18 items**	Mathematical education and literacy
Cluster 2	creative thinking, daily lives, data collection, mathematical communication, mathematical concepts, mathematical problems, mathematical reasoning: **17 items**	Mathematical thinking and communication in daily life
Cluster 3	e-learning, educational computing, educational mathematics, learning mathematics, learning models, learning processes, learning systems, problem based learning: **10 items**	Use of technology and novel teaching methods
Cluster 4	engineering education, financial literacy, mathematics education, reading literacy, science literacy, STEM: **9 items**	Multidisciplinary literacies and their interactions with mathematics education
Cluster 5	functions, mathematical education, mathematical knowledge, mathematical thinking, mathematical teachings: **9 items**	Mathematical knowledge and education
Cluster 6	algebra, design research, development study, formative evaluation, mathematics literacy, potential effects, research methods: **8 items**	Research methods and evaluation in mathematics education
Cluster 7	Indonesia, international students, junior high school, mathematics teacher, school mathematics, teaching and learning: **7 items**	Mathematics education in Indonesia and international settings
Cluster 8	curricula, primary schools, scientific literacy, scientific materials: **4 items**	Development and implementation of the scientific curriculum in primary schools
Cluster 9	gender: **1 item**	Gender

ML Cluster 2: *Mathematical thinking and communication in daily life*

This cluster of terms relates to the ways that mathematical concepts and reasoning can be applied in real-life situations and the importance of effective communication in solving mathematical problems. It relates to the previous one because mathematical thinking also involves creative problem-solving, critical thinking, and reasoning skills. Mathematical communication is used to describe the ability to express mathematical ideas and concepts clearly and effectively.

Mathematical thinking and communication are essential for understanding and solving everyday problems. Mathematical thinking and communication also relate to the ability to collect and interpret data in different aspects of our daily lives, ranging from making informed decisions to solving complex problems [8]. The US National Council of Teachers of Mathematics (NCTM) has carried out studies on mathematical reasoning and communication and averred that they are foundational skills that should be emphasised in mathematics education. By encouraging students to think creatively and communicate effectively, educators can help them develop the problem-solving skills necessary for success in both academic and non-academic settings [38].

ML Cluster 3: *Use of technology and novel teaching methods*

This cluster of terms relates to the use of technology and novel teaching methods to facilitate learning and improve outcomes in mathematics education. It highlights the role of technology and innovative teaching methods in mathematics education and the importance of incorporating research-based practices to improve student outcomes. This is inferred from elements such as e-learning, educational computing, and learning systems, which refer to the use of digital tools and platforms to deliver educational content and support student learning. Problem-based learning and learning models involve active, student-centred approaches that emphasise problem-solving and critical thinking skills. These approaches are necessary to ameliorate the challenges of modern education, such as increasing student engagement and promoting deeper learning [5, 8]. The NCTM further averred that achieving effective mathematics education should be based on research-based practices that incorporate a variety of teaching methods and technologies. Technologies enable educators to create engaging and effective learning environments which can better prepare students for successful lives in the world.

ML Cluster 4: *Multidisciplinary literacies and their interactions with mathematics education*

The theme that summarises this cluster is multidisciplinary literacies and their interactions with mathematics education. This cluster highlights the interconnectedness of mathematics education with other areas of knowledge and skill development. For instance, engineering education and science literacy in the cluster refer to the integration of mathematics with science and engineering disciplines, and financial literacy and reading literacy emphasise the importance of mathematics in real-world applications and everyday life. STEM (Science, Technology, Engineering, and Mathematics) occurs in this cluster, and it is a multidisciplinary approach to education that emphasises the interconnectedness of these fields to mathematical literacy.

ML Cluster 5: *Mathematical knowledge and education*

This cluster of terms highlights the importance of mathematical knowledge and education in the development of mathematical thinking and problem-solving skills. Functions are a fundamental mathematical concept, and the study of functions is central to many areas of mathematics. Mathematical education and teaching refer to the process of acquiring and imparting mathematical knowledge, while mathematical thinking involves the ability to reason and solve problems using mathematical concepts and principles. Mathematical knowledge is an essential component of mathematical literacy, and the acquisition of mathematical knowledge is a key goal of mathematics education. Effective mathematical teaching involves the development of instructional strategies and practices that promote the acquisition of mathematical knowledge and the development of mathematical thinking skills [20].

ML Cluster 6: *Research methods and evaluation in mathematics education*

This cluster of terms highlights the importance of research methods and evaluation in the development and assessment of mathematics literacy. Algebra is a fundamental mathematical concept that is often used to model and solve real-world problems. Mathematics literacy refers to the ability to use mathematical concepts and skills to solve problems in everyday life. Design research and development studies are research methods that are commonly used in mathematics education to develop and evaluate instructional materials and interventions. Formative evaluation is an evaluation method that involves collecting feedback during the development process to improve the quality and effectiveness of instructional materials and interventions. Potential effects in the cluster refer to the possible outcomes or impact of instructional interventions on student learning outcomes. Effective research methods and evaluation techniques can help to identify the potential effects of instructional interventions and inform decisions about the development and implementation of instructional materials and interventions.

ML Cluster 7: *Mathematics education in Indonesia and international settings*

This cluster of terms highlights the context and environment of mathematics education, particularly in Indonesia and international settings. Mathematics education is an essential component of school education and is crucial for developing students' mathematical literacy. Junior high school is a critical period in mathematics education as students develop foundational mathematical concepts and skills. Mathematics teachers play a significant role in the teaching and learning of mathematics and can impact students' attitudes and motivation toward mathematics. School mathematics refers to the mathematics curriculum taught in schools, which can vary across different countries and regions. International students bring diverse perspectives and experiences to mathematics education, highlighting the importance of understanding the cultural and social context of mathematics education.

ML Cluster 8: *Development and implementation of scientific curriculum in the primary schools*

This cluster of terms highlights the importance of designing and implementing effective scientific curricula in primary schools to enhance students' scientific literacy. Scientific literacy is a critical component of mathematics education as it helps students understand the relevance and application of mathematical concepts in real-life situations. Curricula refers to the set of instructional materials, resources, and assessments that guide teaching and learning in primary schools. Effective curricula must be based on sound pedagogical principles and designed to meet the diverse needs and backgrounds of students. Primary schools are an essential site for developing students' mathematical and scientific literacy, as they provide a foundation for learning and skill development. Scientific materials, such as textbooks, laboratory equipment, and other resources, are critical for supporting effective teaching and learning in primary schools.

ML Cluster 9: *Gender*

The presence of the term "gender" in the cluster suggests a focus on exploring the relationship between gender and mathematical literacy. This includes examining gender differences in mathematical achievement, participation, and attitudes towards mathematics. Research indicates persistent gender gaps in mathematics education, with boys often outperforming girls in areas like problem-solving and spatial reasoning, while girls may excel in computation and numeracy. Social norms, cultural expectations, teacher biases, and access to educational resources can influence these differences. Understanding the relationship between gender and mathematical literacy is crucial for promoting equitable access to mathematics education and improving educational quality overall. By identifying and addressing gender-based barriers to learning, schools and educators can create more inclusive and supportive learning environments. The inclusion of "gender" in this cluster underscores its significance in mathematical literacy research and practice, helping educators and researchers better understand challenges and opportunities in fostering equitable mathematics education [4, 7, 11, 21, 32].

Visualisation and mapping of all co-occurrence of keywords on reading literacy, 1974-2022. Based on the occurrences of the keywords, figure 5 and table 5 show that the most frequently occurring keyword is reading literacy, followed by reading, literacy, and PISA. The relative frequency of occurrence of the keywords, a measure of the proportion of times a particular event or keyword occurs relative to the total number of events or keywords observed in a dataset, the focus of reading literacy research are reading comprehension, reading motivation, reading achievement, and digital reading. Additionally, the table highlights the use of different assessment methods, such as PISA (OECD's Programme for International Student Assessment) and PIRLS (IEA's Progress in International Reading Literacy Study), to measure reading literacy as keywords used by researchers.

The cluster also suggests that research on reading literacy encompasses adolescents, children, and adults and examines the various factors that impact reading literacy, such as gender and educational status. The keywords in the table further suggest that e-learning and teaching methods are also areas of interest in reading literacy research.

Cluster analysis of reading literacy keywords. Table 6 shows the analysis of the keywords in each of the eight clusters in reading literacy literature.

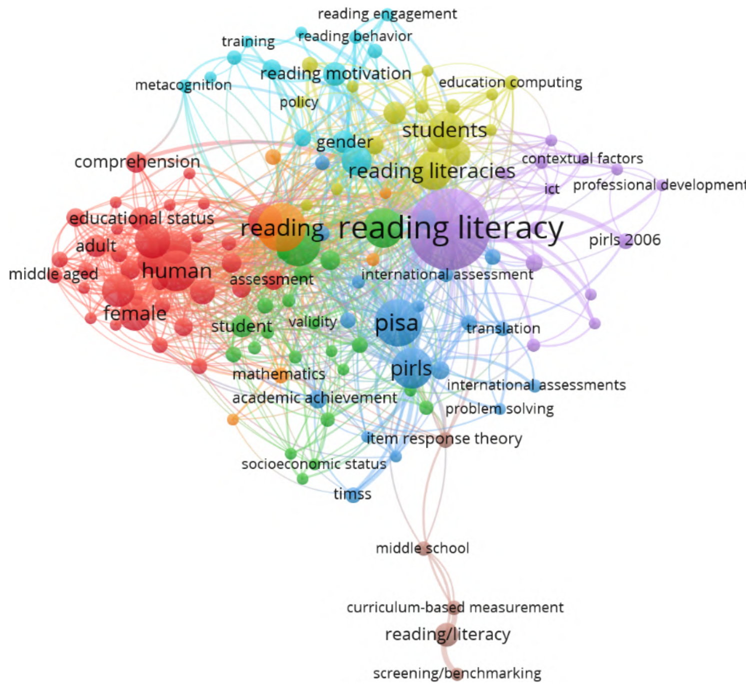

Fig. 5. Visualisation map of all keywords in reading literacy literature 1974-2022.

RL Cluster 1: *Reading cognition and achievement across ages*

The first cluster can be described as addressing reading cognition and achievement across ages. This description encompasses comparative and controlled studies of reading comprehension and assessment, with attention to child and adult readers, cognitive processes, and academic literature analysis. This description also reflects the focus on the understanding of how readers process and make meaning from written language, as well as the use of cognitive and neuroscientific approaches to study reading literacy. Further, the keyword reflects a focus on studying how readers of different ages process and make meaning from written language, with attention to both cognitive and academic factors. Researchers on RL use comparative or controlled studies to understand differences in reading comprehension across age groups. They may also examine cognitive processes like attention and memory to understand better how readers comprehend written text.

RL Cluster 2: *Reading literacy and educational achievement*

The keywords in the second cluster suggest reading literacy and educational achievement as major descriptions. In this description are cross-cultural and large-scale assessments of literacy and decoding skills, with attention to social and educational inequality, intelligence, and cultural capital. It also focuses on

Table 5. Top 30 keywords in reading literacy.

№	Label	Cluster	Links	TLS	Frequency
1	Reading literacy	5	105	147	214
2	Reading	7	93	74	79
3	Pisa	3	71	62	72
4	Literacy	2	79	57	65
5	Pirls	3	50	47	56
6	Human	1	79	55	55
7	Reading comprehension	2	63	42	52
8	Reading literacies	4	43	48	49
9	Students	4	57	44	45
10	Humans	1	71	40	40
11	Education	1	72	38	39
12	Article	1	70	37	37
13	Male	1	64	35	35
14	Female	1	64	34	34
15	Reading achievement	6	22	20	31
16	Adolescent	1	60	22	22
17	Child	1	54	21	21
18	e-Learning	4	29	20	20
19	Reading/literacy	8	21	14	19
21	Reading motivation	6	15	17	18
20	Educational status	1	55	18	18
23	Gender	6	36	15	16
25	Teaching	4	32	16	16
24	Student	2	45	16	16
22	Adult	1	45	16	16
26	Comprehension	1	40	12	15
29	Digital reading	6	21	13	14
28	Controlled study	1	51	14	14
30	Learning	1	43	14	14
27	Assessment	1	24	12	14

reading literacy in Germany and OECD countries. Further, it highlights the importance of cross-cultural and large-scale assessments of reading literacy. It emphasises the role of social and educational inequality, intelligence, and cultural capital in shaping literacy outcomes. The focus on Germany and OECD countries suggests that researchers on this subject are interested in understanding how reading literacy is developed and assessed in specific countries or regions.

RL Cluster 3: *Reading literacy and academic achievement in children*

The third cluster focuses on reading literacy and academic achievement in children. This cluster also highlights a critical methodological subject: longitudinal studies and international comparisons of differential item function and human-computer interaction in large-scale assessments of reading skills. This descrip-

Table 6. Cluster analysis of reading literacy keywords.

Clusters	Items	Description
Cluster 1	Achievement, adolescents, aged, adult, article, assessment, attention, child cognition, comparative study, comprehension, controlled study, cross-sectional study: **36 items**	Reading cognition and achievement across ages
Cluster 2	Academic performance, cultural capital, decoding, educational achievement, educational inequality, Germany, intelligence, large scales assessment, literacy, OECD, social inequality, etc.: **22 items**	Reading literacy and educational achievement
Cluster 3	Academic achievement, children, differential item function, human computer interaction, international assessment, international comparison, longitudinal study: **18 items**	Reading literacy and academic achievement in children
Cluster 4	Computer-aided instruction, curriculum, e-learning, education computing, home literacy environment, international students, international students, learning systems: **17 items**	Technology and reading literacy
Cluster 5	Contextual factors, elementary school, ICT, information technology, learning strategies, mathematical literacy, PIRLS 2006, PIRLS 2016, professional development: **14 items**	Contextual factors and technology in elementary school reading literacy
Cluster 6	Digital reading, evaluation, gender differences, meta cognition, reading achievement, reading attitude, reading behaviour, reading competence, reading engagement: **14 items**	Digital reading and metacognition
Cluster 7	Critical reading, critical thinking, information literacy, mathematics, reading, science: **6 items**	Critical thinking in education
Cluster 8	Curriculum based measurement, item response theory, middle schools, reading/literacy, screening/benchmarking: **6 items**	Middle school reading literacy and curriculum-based measurement

tion highlights the importance of understanding how reading literacy is related to academic achievement in children.

RL Cluster 4: *Technology and reading literacy*

The fourth cluster's technology and reading literacy encompasses computer-aided instruction, e-learning, and educational computing in reading curricula and learning systems. The cluster also touches on the home literacy environment and international students in diverse educational contexts.

RL Cluster 5: *Contextual factors in elementary school reading literacy*

What are the contextual and technological factors that influence elementary school reading literacy? The fifth cluster addresses this question, and it consists of learning strategies and professional development for integrating ICT into mathematical literacy and reading instruction. ICT is actually part of the PIRLS 2006 and 2016 assessments.

RL Cluster 6: *Digital reading and metacognition*

The keywords from the sixth cluster explore the impact of digital reading on reading achievement, reading competence, reading behaviour, and reading engagement while considering gender differences. The keyword focuses on how digital reading impacts different aspects of reading, such as achievement, behaviour, and engagement, while also considering gender differences. They also explore the role of metacognition (i.e., thinking about one's own thinking) and reading attitudes in shaping students' experiences and outcomes related to digital reading.

RL Cluster 7: *Critical thinking in education*

The keywords from the seventh cluster focus on the development of critical thinking skills in students across different subject areas, including reading, science, mathematics, and information literacy. These keywords aim to identify effective instructional strategies and interventions for promoting critical thinking in educational settings.

RL Cluster 8: *Middle school literacy assessment*

This cluster focuses on using curriculum-based measurement and item response theory to assess and improve the reading literacy skills of middle school students. It also aims to screen and benchmark student progress in their reading, and the goal is to identify students who may need additional support and how to track their progress over time. Using these assessment methods and statistical techniques yields a better understanding of how to support middle school students in their course of developing reading skills and achieving proficiency in literacy.

Visualisation and mapping of all co-occurrence of keywords on scientific literacy, 1963-2022. The list of keywords used by researchers to represent research in the area of scientific literacy (table 7) covers an extensive range of topics and issues that are related to scientific knowledge, attitudes towards science, education and communication. The list also covers special issues such as climate change, COVID-19, and sustainability. The list of keywords highlights the importance of STEM education as a critical tool in the development of scientific competencies that could lead to acquiring critical thinking skills and knowledge of the nature of science (figure 6).

The keywords emphasise the role and training of science teachers and the role of developing curricula in promoting scientific literacy among students of different ages and backgrounds. The list also reflects the relevance of socio-scientific issues, such as citizenship, ethics, and social aspects of science, in shaping attitudes and perceptions towards scientific information and evidence. It also emphasises the role of research, data collection, and statistical analysis in advancing scientific literacy and understanding.

Table 7. Top 30 keywords in scientific literacy.

№	Label	Cluster	Links	TLS	Frequency
17	Curriculum	6	96	46	49
12	Science	5	127	71	73
1	Scientific literacy	4	232	752	935
4	Science education	4	125	133	150
8	Nature of science	4	81	89	101
23	Socio-scientific issues	4	53	38	44
29	Pisa	4	35	34	38
27	Socioscientific issues	4	33	37	39
5	Education	3	187	128	132
11	Teaching	3	133	77	79
20	Climate change	3	96	45	47
18	Engineering education	3	70	49	49
19	Science communication	3	70	43	48
2	Students	2	202	300	301
9	Science literacy	2	141	81	90
0	Education computing	2	103	81	81
25	Surveys	2	85	40	41
28	Physics	2	71	38	38
26	Junior high schools	2	61	40	40
7	Literacy	1	153	105	107
3	Human	1	140	151	151
6	Humans	1	133	116	116
14	Student	1	128	63	63
13	Article	1	122	63	63
15	Female	1	120	58	58
16	Male	1	119	57	57
22	Knowledge	1	111	42	44
24	Adult	1	111	41	41
21	Learning	1	108	44	45

Cluster analysis of scientific literacy keywords. Table 8 shows the analysis of the clusters of scientific literacy keywords.

SL Cluster 1: *Cross-cultural health attitudes*

The keywords in this cluster suggest a focus on understanding and comparing the attitudes of people towards health and biology across different cultures, as well as exploring the roles communication and comprehension play in the shaping of these attitudes. There is an observation of age-specific keywords such as adolescent, adult, aged, and child, and this suggests that there is an interest in examining how attitudes evolve across the human lifespan.

SL Cluster 2: *Exploring effective learning strategies*

This cluster can be summarised as addressing effective learning strategies. They also address educational research in relation to collaborative learning, e-learning,

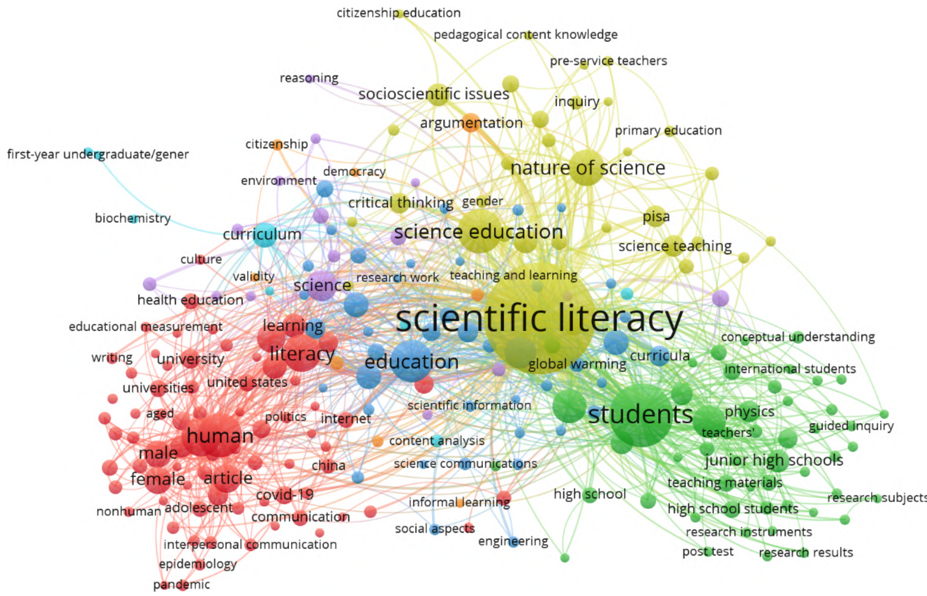

Fig. 6. Visualisation map of all keywords in scientific literacy literature (1974-2022).

and data analysis techniques. Furthermore, the keywords touch experimental research with particular respect to the effectiveness of various learning strategies and techniques, as well as data collection and management approaches. There is also a focus on "conceptual understanding" and how students learn, develop, and apply conceptual knowledge in their various learning contexts.

SL Cluster 3: *Scientific literacy and education*

In this cluster, diverse topics related to scientific literacy are included. These include the study of human behaviour, public participation in scientific research, understanding science in the context of societal issues, and climate change. Other issues include mental processes and abilities, the use of technology for teaching, theoretical structures, course content plans, decision-making, education, and some fields of study, such as employment and engineering.

SL Cluster 4: *Scientific literacy for critical thinking*

These keywords encompass various aspects of science education and literacy, including the assessment of learning, attitudes towards science, teaching and learning biology, education for informed citizenship, critical thinking skills, education at early ages, the influence of media, motivation to learn, gender differences, active learning and investigation, the process of gaining scientific knowledge, understanding how science works, and international assessments of student performance (PISA).

Table 8. Cluster analysis of scientific literacy keywords.

Clusters	Items	Description
Cluster 1	Adolescent, adult, aged, article, attitude, attitude to health, biology, child, China comparative study, communication, comprehension, culture, educational measurement: **237 items**	Cross-cultural health attitudes
Cluster 2	Collaborative learning, conceptual understanding, data analysis technique, data collection, data handling, e-learning, education computing, experimental research, experimental groups: **51 items**	Exploring effective learning strategies
Cluster 3	Behavioural research, citizen science, civic scientific literacy, climate change, cognition, computer aided instruction, conceptual framework, curricula, decision making, diversity, earth science, education, employment, engineering: **44 items**	Science literacy, varied topics
Cluster 4	Assessment, attitudes, biology education, citizenship education, critical thinking, elementary school, media, motivation, gender, inquiry, learning science, nature of science, pisa, pre-service teacher: **33 items**	Science education for critical thinking
Cluster 5	Active learning, environment, evolution, health, higher education, information science, pseudoscience, reasoning, religion, science, science learning, science education, stem, systematic review, teaching and learning: **17 terms**	Comprehensive, multidisciplinary, critical-thinking
Cluster 6	Big data, biochemistry, content analysis, curriculum, first year undergraduate, inquiry based/discovery, qualitative analysis, science teachers: **8 items**	Multidisciplinary scientific literacy development
Cluster 7	Argumentation, citizenship, democracy, evaluation, informal learning, scientific reasoning, social media, validity: **8 items**	Scientific literacy and civic engagement

SL Cluster 5: *Comprehensive multidisciplinary critical thinking*

This cluster represents various aspects of scientific literacy, with a focus on teaching and learning. The topics covered include environmental science, evolution, health, pseudoscience, religion, and STEM education, among others. The cluster also emphasises the importance of critical thinking and reasoning in developing scientific literacy. The inclusion of higher education and information science suggests that scientific literacy is relevant to a broad range of disciplines and fields. The cluster highlights the need for a multidisciplinary and comprehensive approach to addressing scientific literacy to foster active learning and critical examination.

SL Cluster 6: *Multidisciplinary scientific literacy development*

This cluster suggests that scientific literacy requires the incorporation of data analysis, inquiry-based learning, and effective teaching strategies in various scientific fields. It highlights the need to support students and teachers in their endeavours in scientific literacy in order to foster a deeper understanding of the scientific literacy landscape. Scientific literacy incorporates big data and content analysis, encompassing teaching students how to use and analyse large datasets to understand complex scientific phenomena. It also concerns itself with the understanding of the role of biochemistry in science education, such as teaching students the fundamental principles of biochemistry and its application to various other aspects of the learning need. Further, the cluster contains issues that relate to encouraging students to ask questions and explore scientific concepts through hands-on experimentation and discovery and using qualitative research methods to examine and understand how students learn science in order to improve science literacy education. The cluster further addresses how to empower science teachers with relevant skills and resources for effective teaching of science.

SL Cluster 7: *Scientific literacy and civic life*

This cluster highlights several studies, mainly in the 21st century, that address the role of scientific literacy as an important tool for effective engagement in civic life, beyond personal development. Scientific literacy incorporates the ability of an individual to critically evaluate scientific information and engage in argumentation and scientific reasoning, as well as the ability to navigate social media platforms to acquire required information. In this respect, the cluster unveils the fact that scientific literacy is closely related to various aspects of civic life, such as democracy and citizenship. The cluster highlights the importance of developing skills in argumentation, scientific reasoning, and evaluation to engage with scientific information effectively. Finally, the cluster emphasises the importance of understanding the concept of validity in scientific research and how to evaluate scientific claims in a social and political context critically.

4 Discussion of findings

This study used a bibliometric visualisation of the literature to examine the volume and growth of the literature on reading literacy (1974-2022), scientific literacy (1963-2022), and mathematical literacy (1961-2022) indexed in the Scopus database. The study also analysed the document types of the literacies so as to understand the scope of research in the area. Finally, the study mapped the keywords used by authors and indexers to represent the literature in the various years of coverage of the literature in each of the literacies.

Of the literature in three literacies, research on reading literacy is the youngest, although Leeds [17] reported that Smith [31] has dated reading instructions to 1607. However, efforts at reading literacy have ancient origins dating back to the emergence of written languages and civilisations – the earliest forms of reading involved deciphering hieroglyphics, cuneiform scripts, and other ancient writing systems. While there was a rise in the quantity of literature in 1993, the actual takeoff of research on the subject can be traced to 2002. Mathematical literacy is the oldest, but a visible takeoff was in about 2003; scientific literacy is the next oldest (1963).

According to Niss and Jablonka [23, p. 1] "one of the first written occurrences of the term mathematical literacy was in 1944 in the USA, when a Commission of the National Council of Teachers of Mathematics on Post-War Plans [13, p. 244] required that the school should ensure mathematical literacy for all who can achieve it. Shortly after (in 1950), the term was used again in the Canadian Hope Report [13, p. 401]". The rise in publication growth in the area can be traced to around 1996. The trend in publications in the three subjects is highest for reading literacy ($R2 = 0.712$) while it is lowest for mathematical literacy ($R2 = 0.482$).

Analysing the quantities and percentages allows us to discern the prominence of different document types within each category, providing insights into the composition of literacy-related materials and the emphasis placed on different forms of literacy. As absolute figures, scientific literacy has a larger quantity of documents than other literacies, about as proportions of their totals, reading literacy has more articles (78.56%) than scientific literacy (65.14%) and mathematical literacy (51.57%). However, mathematical literacy (32.58%) has more conference reports than reading literacy (7.87%) and scientific literacy (16.94%), but scientific literacy has documents in all the document types in Scopus, unlike RL and mathematical literacy with no documents on note, letter and short surveys.

By frequency of occurrences of the keywords "mathematical literacy" (181), "students" (143) and "mathematics education" (45) are most occured; by total link strength, "students" (138), "mathematical literacy" (110) and "mathematics education" (41). By links, "students" (74), "mathematical literacy" (55) and "mathematical education" (54) were the top keywords. Mathematical literacy as an educational component has been focused on junior high school students, with the curriculum being a critical issue.

Mathematical literacy alone has nine clusters, higher than the other literacies. While the number of clusters of keywords associated with a particular literacy does not necessarily indicate its importance or value, mathematics is a highly structured and abstract discipline that deals with precise concepts and relationships. As a result, mathematical literacy involves a wide range of mathematical keywords and symbols that represent specific mathematical ideas, operations, and techniques. The complex nature of mathematics leads to a larger number of clusters of keywords. The complex nature of mathematics often requires breaking down problems into smaller components and employing various mathematical concepts and tools, leading to a greater number of clusters of keywords. Niss and Jablonka [23] captured this diversity and complexity of mathematical literacy in their essay.

The findings presented in the study, particularly the analysis of keywords and their clustering, provide valuable insights into the multifaceted nature of mathematical literacy and its various dimensions within the realm of mathematics education. The study highlights that mathematical literacy is a complex and multifaceted concept. It encompasses not only mathematical concepts and problem-solving skills but also various other dimensions, including teaching methods, assessment practices, curriculum design, and its integration with other scientific and technical fields. The presence of keywords related to engineering education, physics, STEM, and other scientific disciplines suggests that mathematical literacy is closely connected to other domains of knowledge. This finding underscores the importance of promoting interdisciplinary learning and recognising the role of mathematics in various real-world contexts.

The identification of keywords like “teaching”, “students”, “mathematics education”, and “problem solving” underscores the significance of effective teaching and learning strategies in developing mathematical literacy. It emphasises that mathematical literacy is not solely about content knowledge but also about how mathematics is taught and learned. The inclusion of keywords such as “e-learning”, “education computing”, and “learning systems” highlights the increasing role of technology in mathematics education. It raises discussions about the integration of technology in teaching mathematics and its impact on students' mathematical literacy. The presence of keywords like “assessment” and “PISA” points to the importance of measuring and evaluating mathematical literacy. This raises discussions about the methods and tools used to assess mathematical literacy and their implications for educational policies and practices. The study mentions the importance of understanding the cultural and social context of mathematics education, especially in international settings like Indonesia. This emphasises the need for culturally responsive mathematics education and addressing the diversity of experiences and perspectives among students.

With respect to reading literacy, and considering the frequency of occurrence of the keywords, “reading literacy” (214), “reading” (79) and “PISA” (72) are the major three keywords. This sequence of keywords remains the same with respect to total link strength, while with respect to links, “reading literacy” (105), “reading” (93), and “literacy” (79) have the highest frequencies. With regards to clusters, “gender” is the keyword with the third highest frequency, following reading literacy and reading. Reading literacy is not a major skill for high school students; it is for everybody, but gender patterns are a very important consideration. Reading literacy has eight clusters; reading literacy primarily focuses on the ability to comprehend and interpret written texts, including various genres such as fiction, non-fiction, poetry, and more. It involves understanding the meaning, context, and structure of written materials, irrespective of their fields and subjects. Wu and Peng [37] and Lan and Yu [16] examined the breadth of issues involved in reading literacy, and they are sufficient to justify a large number of clusters of keywords.

Reading literacy research highlights the importance of understanding how readers of different ages, including children and adults, process and comprehend written language. Researchers in this area conduct comparative and controlled studies to explore differences in reading comprehension across age groups. This suggests that reading literacy research is not limited to one specific age group but spans across the lifespan. It also emphasises the relationship between reading literacy and educational achievement. Researchers in this area investigate the role of cultural capital, intelligence, and social inequality in shaping literacy outcomes. They also conduct cross-cultural assessments, indicating a global perspective on reading literacy and its impact on academic success. Reading literacy addresses the relationship with academic achievement, specifically in children. This suggests a particular interest in understanding how early literacy skills are linked to overall academic success. The use of longitudinal studies and international comparisons highlights a commitment to rigorous research methodologies.

Reading literacy also explores the integration of technology, such as e-learning and educational computing, into reading curriculum and learning systems. It indicates a recognition of the role of technology in shaping how reading is taught and learned in contemporary educational settings. It also concerns the contextual factors that influence elementary school reading literacy. This includes strategies for integrating ICT into reading instruction. The consideration of professional development suggests a focus on teacher training and capacity building.

Reading literacy has also addressed the issue of the impact of digital reading on various aspects of reading, including achievement, behaviour, engagement, and competence. It also considers gender differences and the role of metacognition. This reflects the evolving landscape of reading literacy in the digital age. The broadening of the scope of reading literacy to encompass critical thinking skills across different subject areas relates to the foundational role of critical reading, identifying, in addition, effective instructional strategies for promoting critical thinking, which is a crucial component of reading literacy and broader education. The issues of assessing and improving reading literacy skills among middle school students and the use of curriculum-based measurement and item response theory provide insights into effective assessment methods for tracking student progress and identifying those in need of additional support.

"Scientific literacy" dominated the other keywords in respect of occurrences (935), but "students" (301) and "human" (151) have high occurrences. These three keywords remain outstanding in respect of total link strength; "scientific literacy" (232), "education" (202), and "students" (187) had the highest number of links. We infer that scientific literacy is not only for students but for all humans, as we all need some scientific capacity to address basic issues in our lives. A curriculum for facilitating scientific literacy is crucial in ensuring efficient achievement. Despite being a wide area of literacy, scientific literacy has the lowest number of clusters, with each of the clusters capturing a key aspect of scientific literacy.

The cluster analysis of keywords in the field of scientific literacy provides a comprehensive view of the various facets and research areas within this domain. Scientific literacy is a multidimensional concept encompassing not only knowledge of science but also attitudes, communication, education, and critical thinking. Scientific literacy addresses the importance of understanding how attitudes towards health and biology vary across different cultures. It also highlights the role of communication and comprehension in shaping these attitudes. The inclusion of age-specific keywords suggests an interest in examining how attitudes evolve over a person's lifespan, which is crucial for tailoring science education and communication strategies. It also focuses on effective learning strategies in the context of scientific literacy. It includes collaborative learning, e-learning, and experimental research, indicating a commitment to exploring innovative educational methods. The emphasis on "conceptual understanding" underscores the significance of not only acquiring scientific knowledge but also comprehending and applying it effectively.

Also, scientific literacy touches on a wide range of topics related to scientific literacy, including the study of human behaviour, public participation in scientific research, societal issues, and climate change. It also touches on technology use, decision-making processes, and education in various fields such as employment and engineering. This cluster reflects the diverse and interdisciplinary nature of scientific literacy research. It also encompasses aspects of science education and literacy critical for informed citizenship. It includes assessing learning, understanding attitudes towards science, and promoting critical thinking skills. The importance of early education, media influence, and motivation in fostering scientific literacy is evident.

Additionally, international assessments like PISA are acknowledged as important benchmarks. Scientific literacy also represents a comprehensive and multidisciplinary approach to scientific literacy. It touches on diverse subjects, including environmental science, evolution, health, and pseudoscience, while emphasising the significance of critical thinking and reasoning. The inclusion of higher education and information science underscores the relevance of scientific literacy in a wide range of fields.

Finally, scientific literacy highlights the need for a multidisciplinary approach to scientific literacy development. It promotes data analysis, inquiry-based learning, and effective teaching strategies across various scientific disciplines. It also emphasises the importance of empowering science teachers with the necessary skills and resources for effective science education. Scientific literacy also delves into the role of scientific literacy in civic life, emphasising its importance beyond personal development. It highlights skills such as argumentation, scientific reasoning, and the ability to evaluate scientific information critically. Civic engagement, democracy, and citizenship are central themes, indicating that scientific literacy is vital for informed and active participation in society.

5 Conclusion

This research presents a bibliometric analysis of the literature on reading literacy (1974-2022), scientific literacy (1963-2022) and mathematical literacy (1961-2022). The analysis revealed several key insights into the development and trends within these literacy domains. Reading literacy, although with historical references dating back centuries, experienced a notable surge in research activity in the early 2000s. This suggests a growing recognition of the importance of reading literacy across various fields and contexts. Additionally, reading literacy was found to encompass a diverse range of topics and issues, including gender-related patterns, making it a subject of broad interest and research.

Mathematical literacy, as the oldest of the three literacies, saw a visible increase in research attention around 2003. This may be attributed to the recognition of the critical role of mathematical literacy in education and its importance in various stages of schooling, especially among junior high school students. The complexity of mathematics was evident through the multitude of keyword clusters associated with this literacy. Scientific literacy, while having historical references, witnessed a significant growth in publications around 1996. This underscores the recognition that scientific literacy is not limited to students but is essential for all individuals in addressing fundamental issues in their lives. The study highlighted the importance of curriculum development in facilitating efficient achievement of scientific literacy. The analysis of document types emphasised the prominence of different types of documents within each literacy category, shedding light on the diversity of materials available for research and learning purposes.

The analysis of the keywords and their clustering underscores the intricate nature of mathematical literacy as a concept and its far-reaching impact on education and society. Mathematical literacy encompasses not only mathematical knowledge and problem-solving skills but also teaching methods, assessment practices, interdisciplinary connections, and the influence of technology. It highlights the need for a holistic approach to mathematics education that considers various dimensions of mathematical literacy. Moreover, the study suggests that promoting mathematical literacy involves not only imparting mathematical content but also fostering critical thinking, communication skills, and the ability to apply mathematical concepts in real-life situations. It calls for educators to adopt innovative teaching methods and consider the cultural and contextual factors that influence students' learning experiences.

The study's findings highlight the evolving landscape of research and scholarship in reading literacy, mathematical literacy, and scientific literacy. These key literacies continue to be of great importance in education and society at large, reflecting their critical role in equipping individuals with the skills and knowledge necessary to navigate the complexities of the modern world. As research in these areas continues to evolve, educators, policymakers, and researchers must remain attentive to the changing dynamics and challenges within these domains to ensure effective literacy development for all individuals.

Reading literacy research spans different age groups, explores the relationship between literacy and academic achievement, considers the influence of technology and contextual factors, and addresses critical thinking skills. It also recognises the need to assess and support reading skills, especially among middle school students. The findings suggest that reading literacy is a dynamic and evolving field that encompasses various aspects of literacy development, teaching practices, and assessment methods. Researchers in this domain employ a wide range of methodologies and perspectives to advance our understanding of how reading literacy impacts individuals across different stages of life and educational settings. These insights are invaluable for educators, policymakers, and researchers seeking to enhance reading literacy and promote effective literacy education in diverse contexts.

The analysis of scientific literacy keywords demonstrates that scientific literacy is a complex and multifaceted concept. It encompasses not only the acquisition of scientific knowledge but also attitudes, communication, critical thinking, and its role in education and civic life. Researchers in this field employ diverse methodologies and perspectives to investigate and promote scientific literacy. The findings highlight the need for a holistic approach to scientific literacy education, one that fosters critical thinking, effective communication, and an understanding of the societal implications of science. Scientific literacy is not limited to any specific age group or discipline; it is a skill set that empowers individuals to engage with scientific information, make informed decisions, and contribute to the betterment of society. This research is invaluable for educators, policymakers, and researchers seeking to enhance scientific literacy and promote its broader societal benefits.

5.1 Limitations

This study relied on the Scopus database, which, as previously mentioned, may have limitations in terms of coverage and language bias. The analysis covers a specific timeframe for each literacy area, and there is evidence that research on these subjects predated published indexed literature. Also, the analysis mentioned document types, but the study did not delve into the quality or impact of the documents. A future study could assess the significance of various document types in each literacy area. Apart from mentioning that research on literacy is multidisciplinary, it did not explore the extent of interdisciplinary collaboration or the impact of such collaborations on the field. Future research could investigate these aspects in more detail. Finally, the keyword analysis provided valuable insights but did not delve into the semantics or context of how keywords are used in the literature. Understanding the nuanced meanings of keywords and their evolution over time could be an interesting avenue for further investigation.

5.2 Future research considerations

Conducting a longitudinal analysis to track how research trends and priorities have evolved over a more extended period could provide a deeper understanding of the trajectory of these literacy areas. Also, comparing research on different types of literacy, such as reading literacy, scientific literacy, and mathematical literacy, could yield insights into commonalities and differences in research themes and methodologies. It will be interesting to explore the geographical distribution of research on literacy topics, and assessing regional variations in research focus and impact could be informative. Impact assessment and integration of emerging technologies are issues that would benefit from further studies on the subject.

References

[1] Ahyan, S., Turmudi, T., Juandi, D.: Bibliometric analysis of research on mathematical literacy in Indonesia. Journal of Physics: Conference Series **1869**(1), 012120 (apr 2021), https://doi.org/10.1088/1742-6596/1869/1/012120

[2] Beecher, C.: Chapter 1. What is Literacy? Multiple Perspectives on Literacy. In: Methods of Teaching Early Literacy, pp. 2–21, Iowa State University, Ames, Iowa (2023), URL https://iastate.pressbooks.pub/teachingearlyliteracy/open/download?type=pdf

[3] Chen, X., Zhou, J., Wang, J., Wang, D., Liu, J., Shi, D., Yang, D., Pan, Q.: Visualizing Status, Hotspots, and Future Trends in Mathematical Literacy Research via Knowledge Graph. Sustainability **14**(21), 13842 (2022), https://doi.org/10.3390/su142113842

[4] Cheryan, S., Plaut, V.C.: Explaining Underrepresentation: A Theory of Precluded Interest. Sex Roles **63**(7), 475–488 (Oct 2010), https://doi.org/10.1007/s11199-010-9835-x

[5] Cross, C.T., Woods, T.A., Schweingruber, H. (eds.): Mathematics Learning in Early Childhood: Paths Toward Excellence and Equity. National Academies Press, Washington, D.C. (2010), URL https://tinyurl.com/zjja8jzc

[6] De Bellis, N.: Bibliometrics and Citation Analysis: From the Science Citation Index to Cybermetrics. The Scarecrow Press, Inc., Lanham, Maryland; Toronto; Plymouth, UK (2009)

[7] Else-Quest, N.M., Hyde, J.S., Linn, M.C.: Cross-national patterns of gender differences in mathematics: A meta-analysis. Psychological Bulletin **136**(1), 103–127 (Jan 2010), https://doi.org/10.1037/a0018053

[8] English, L.D., Ärlebäck, J.B., Mousoulides, N.: Reflections on Progress in Mathematical Modelling Research. In: Gutiérrez, Á., Leder, G.C., Boero, P. (eds.) The Second Handbook of Research on the Psychology of Mathematics Education: The Journey Continues, pp. 383–413, SensePublishers, Rotterdam (2016), https://doi.org/10.1007/978-94-6300-561-6_11

[9] Gaskell, R.E.: A must for the future: Universal mathematical literacy. Theory Into Practice **3**(2), 49–53 (1964), https://doi.org/10.1080/00405846409541890

[10] Hopkins, C.E., Berry, V.B.: On the Mathematical Literacy of Medical Students. Journal of Medical Education **36**(4), 338–341 (Apr 1961), URL https://journals.lww.com/academicmedicine/citation/1961/04000/on_the_mathematical_literacy_of_medical_students.5.aspx

[11] Hyde, J.S., Fennema, E., Lamon, S.J.: Gender differences in mathematics performance: A meta-analysis. Psychological Bulletin **107**(2), 139–155 (1990), https://doi.org/10.1037/0033-2909.107.2.139

[12] Jonas, N., Thorn, W.: Literacy skills and family configurations. OECD Education Working Papers 192, OECD Publishing, Paris (2018), https://doi.org/10.1787/509d788a-en
[13] Jones, P.S., Coxford, Jr., A.F. (eds.): A History of Mathematics Education in the United States and Canada: Thirty-second Yearbook. National Council of Teachers of Mathematics, Washington, D.C. (1970)
[14] Kaiser, G., Sriraman, B.: A global survey of international perspectives on modelling in mathematics education. ZDM **38**(3), 302–310 (Jun 2006), https://doi.org/10.1007/BF02652813
[15] Karatza, S.: Multimodal literacy and language testing: Visual and intersemiotic literacy indicators of reading comprehension texts. Journal of Visual Literacy **39**(3-4), 220–255 (2020), https://doi.org/10.1080/1051144X.2020.1826222
[16] Lan, X., Yu, Z.: A Bibliometric Review Study on Reading Literacy over Fourteen Years. Education Sciences **13**(1), 27 (2023), https://doi.org/10.3390/educsci13010027
[17] Leeds, D.S.: Sociology of reading: Literacy and language. Reading World **14**(1), 71–82 (1974), https://doi.org/10.1080/19388077409557256
[18] Lesh, R.A., Doerr, H.M. (eds.): Beyond Constructivism: Models and Modeling Perspectives on Mathematics Problem Solving, Learning, and Teaching. Routledge, New York (May 2003), https://doi.org/10.4324/9781410607713
[19] Muslimah, H., Pujiastuti, H.: Analisis Kemampuan Literasi Matematis Siswa dalam Memecahkan Masalah Matematika Berbentuk Soal Cerita. Jurnal Pendidikan Matematika dan Sains **8**(1), 36–43 (Apr 2021), https://doi.org/10.21831/jpms.v8i1.30000
[20] National Council of Teachers of Mathematics: Principles and Standards for School Mathematics. The National Council of Teachers of Mathematics, Inc., Reston, VA (2000), URL https://tinyurl.com/4hua7mmn
[21] National Council of Teachers of Mathematics: Catalyzing Change in High School Mathematics: Initiating Critical Conversations. The National Council of Teachers of Mathematics, Inc., Reston, VA (2018)
[22] Nguyen, L.H.T., Vo, M.T.H., Tran, L.T.M., Dadaczynski, K., Okan, O., Murray, L., Van Vo, T.: Digital Health Literacy About COVID-19 as a Factor Mediating the Association Between the Importance of Online Information Search and Subjective Well-Being Among University Students in Vietnam. Frontiers in Digital Health **3** (2021), https://doi.org/10.3389/fdgth.2021.739476
[23] Niss, M., Jablonka, E.: Mathematical Literacy. In: Lerman, S. (ed.) Encyclopedia of Mathematics Education, pp. 391–396, Springer Netherlands, Dordrecht (2014), ISBN 978-94-007-4978-8, https://doi.org/10.1007/978-94-007-4978-8_100
[24] Nwagwu, W.E., Williams, C.B.: Knowledge mapping and visualization of personal information management literature, 1988–2020. IFLA Journal **48**(4), 598–621 (2022), https://doi.org/10.1177/03400352211065487
[25] OECD: Measuring Student Knowledge and Skills: A New Framework for Assessment. OECD Publications Service, Paris (1999), https://doi.org/10.1787/9789264173125-en

[26] OECD: PISA 2018 Reading Framework. In: PISA 2018 Assessment and Analytical Framework, chap. 2, pp. 21–71, OECD Publishing, Paris (Aug 2019), https://doi.org/10.1787/b25efab8-en

[27] OECD: PISA 2018 Results, vol. I: What Students Know and Can Do. OECD Publishing, Paris (Dec 2019), https://doi.org/10.1787/5f07c754-en

[28] OECD: OECD Skills Outlook 2023: Skills for a Resilient Green and Digital Transition. OECD Publishing, Paris (2023), https://doi.org/10.1787/27452f29-en

[29] Roit, M.L., Pfohl, W.: The Readability of P.L. 94–142 Parent Materials: Are Parents Truly Informed? Exceptional Children **50**(6), 496–505 (1984), https://doi.org/10.1177/001440298405000602

[30] Schotten, M., el Aisati, M., Meester, W.J.N., Steiginga, S., Ross, C.A.: A Brief History of Scopus: The World's Largest Abstract and Citation Database of Scientific Literature. In: Cantu-Ortiz, F.J. (ed.) Research Analytics: Boosting University Productivity and Competitiveness through Scientometrics, p. 31–58, Auerbach Publications, New York (Oct 2017), https://doi.org/10.1201/9781315155890-3

[31] Smith, N.B.: American reading instruction: its development and its significance in gaining a perspective on current practices in reading. International Reading Association, Newark, Delaware (1965)

[32] Suprapto, E., Suryani, N., Siswandari, S., Mardiyana, M.: Students' mathematical literacy skill in term of gender differences: A comparative study. International Journal of Evaluation and Research in Education (IJERE) **12**(4), 2280 (Dec 2023), https://doi.org/10.11591/ijere.v12i4.27224

[33] United Nations: The 17 Goals | Sustainable Development (2024), URL https://sdgs.un.org/goals

[34] Van Eck, N.J., Waltman, L.: VOSviewer Manual. Universiteit Leiden (2023), URL https://www.vosviewer.com/documentation/Manual_VOSviewer_1.6.20.pdf

[35] Visser, M., van Eck, N.J., Waltman, L.: Large-scale comparison of bibliographic data sources: Scopus, Web of Science, Dimensions, Crossref, and Microsoft Academic. Quantitative Science Studies **2**(1), 20–41 (04 2021), https://doi.org/10.1162/qss_a_00112

[36] Wittlin, A.S.: Scientific literacy begins in the elementary school. Science Education **47**(4), 331–342 (1963), https://doi.org/10.1002/sce.3730470404

[37] Wu, J.Y., Peng, Y.C.: The modality effect on reading literacy: perspectives from students' online reading habits, cognitive and metacognitive strategies, and web navigation skills across regions. Interactive Learning Environments **25**(7), 859–876 (2017), https://doi.org/10.1080/10494820.2016.1224251, URL https://www.researchgate.net/publication/308012913

[38] Yang, Z., Wen, H., Bai, Y.: Reading Literacy, Scientific Literacy and Mathematical Literacy's Influence on Students' Academic Achievements. Journal of Higher Education Research **2**(6), 389–393 (Dec 2021), https://doi.org/10.32629/jher.v2i6.575