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Insights into M-learning in Mathematics Education: A Bibliometric Study from 2007 to 2024

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Mobile learning (M-learning) has emerged as a transformative approach in mathematics education. This approach provides flexible access to educational resources. Consequently, there was a need to conduct a bibliometric analysis to understand trends, key contributors, and research themes in the field of M-learning, particularly in the context of mathematics education and this study included 74 publications covering the years 2007-2024. Analytical tools such as biblioMagika® were used for metric calculations, OpenRefine for data cleaning, and VOSviewer for network visualization. The results of the bibliometric analysis reveal a significant increase in M-learning research after 2020. This growth is driven by the implementation of distance learning due to the COVID-19 pandemic. Among the countries contributing significantly are Indonesia, the United States, and Germany. Additionally, institutions like the University of Rijeka and Utah State University play key roles in this research. Previous studies also identify several main themes. These themes include engagement strategies, cognitive skill development, and collaborative learning. Frequently used keywords include "mobile learning", "mathematics education", and "game-based learning. The analysis indicates an h-index of 18 and a citation rate per publication of 13.55. Both metrics reflect the impact and academic engagement within this field. This comprehensive overview of M-learning in mathematics education provides valuable guidance for researchers, educators, and policymakers. The study also encourages continued exploration of M-learning's potential to enhance mathematics learning outcomes globally.

Keywords: m-learning, mathematics education, bibliometric analysis, mobile, learning

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INTRODUCTION

The Fourth Industrial Revolution has significantly impacted mathematics education, driving the need for innovative, flexible, and technology-based approaches to meet modern learning demands (Güler et al., 2022). Mobile learning (M-learning) has emerged as a transformative method within mathematics education, offering students accessible and interactive ways to engage with mathematical concepts. With its capacity to deliver content via smartphones, tablets, and other portable devices, M-learning enables students to explore mathematics beyond traditional classroom settings, aligning with the need for digital literacy and adaptability in contemporary education (Burke et al., 2022). By supporting personalized learning and on-demand access, M-learning addresses essential competencies for success in a knowledge-based economy, where proficiency in mathematical problem-solving and technological skills are increasingly valued (Murtiyasa et al., 2020).

The role of M-learning in mathematics education has proven particularly effective in enhancing engagement and motivation through interactive, gamified, and visual learning tools. Research shows that M-learning can improve mathematics learning outcomes by making complex mathematical ideas more accessible and engaging, especially when students encounter abstract concepts that benefit from visual representation and interactivity (Istikomah & Herlina, 2020). During the COVID-19 pandemic, the importance of M-learning grew exponentially as schools and universities turned to digital platforms for remote education. This shift underscored M-learning's potential in maintaining academic continuity, allowing students to continue their mathematics studies and remain connected to learning communities despite physical barriers (Johnson et al., 2022).

M-learning's flexibility is also evident across diverse educational contexts and regions, including both developed and developing nations. In mathematics education, this flexibility addresses accessibility challenges by enabling students in remote or underserved areas to engage with quality resources. Countries like Indonesia, the United States, and Germany have utilized M-learning to bridge educational gaps and support students' mathematical learning journeys (Wang et al., 2021). This adaptability supports differentiated learning, accommodating students' unique learning speeds and needs, which is particularly beneficial for complex subjects like mathematics. Moreover, M-learning applications in mathematics education encourage collaborative learning, allowing students to work together on problem-solving activities in virtual environments (Panteli & Panaoura, 2020).

Considering the significant growth in M-learning research within mathematics education, a bibliometric analysis is necessary to map the research landscape comprehensively. Such an analysis would identify research trends, key contributors, influential studies, and prevalent themes within M-learning for mathematics education, offering insights into its academic impact and practical applications (Zhao & Chen, 2023). This bibliometric overview will highlight areas for further investigation, supporting educators, researchers, and policymakers in developing strategies to leverage M-learning effectively in mathematics. With M-learning's role in mathematics education expanding rapidly, especially after the COVID-19 pandemic, a bibliometric analysis will provide a structured understanding of the field, fostering continued exploration of M-learning's potential to enhance mathematics learning outcomes worldwide.

Literature Review

The introduction of mobile learning (M-learning) in mathematics education represents a significant shift in instructional methods, student engagement, and access to resources. M-learning provides flexible, on-demand access to educational materials, enabling students to engage with mathematical concepts outside of the traditional classroom. M-learning technologies such as interactive apps, game-based learning modules, and simulations offer a more adaptable approach to mathematics education (Tang et al., 2023; Uribe-Hernández et al., 2020). These tools support a learner-centered experience, breaking through conventional limitations by facilitating real-time feedback, personalized learning paths, and ostudy. Keyfor self-directed study.

Key features of the most compelling examples of M-learning's impact in mathematics education is the use of gamified applications, which transform mathematical problem-solving into interactive challenges. These applications are more than just supplements. They redefine the learning experience by merging mathematics with entertainment, thereby increasing student engagement and motivation. Studies show that gamified M-learning applications significantly improve student retention and interest in mathematics, with increased motivation levels as high as 35% (Tah et al., 2024). The integration of M-learning apps designed to present mathematical problems in a game format represents a pivotal evolution in mathematics instruction, highlighting the shift towards adaptive and interactive learning platforms (Shyshenko et al., 2021).

Interest in M-learning in mathematics education has surged, reflecting both practical and academic interest in its potential benefits. Recent studies underscore M-learning's effectiveness in developing higher-order thinking skills (HOTs) as interactive problem-solving modules encourage students to explore, analyse, and synthesise mathematical concepts more thoroughly (Jatileni et al., 2024a; Tian & Wahid, 2024). Platforms designed around HOTs facilitate advanced cognitive engagement by requiring students to apply knowledge in real-world scenarios, rather than through rote memorization alone. This aligns well with educational goals, which increasingly emphasise critical thinking, problem-solving, and logical reasoning as core competencies in mathematics education (Ibrahim et al., 2023; Sosa-Gutierrez et al., 2024).

Previous Studies on Bibliometric Analysis

The application of bibliometric analysis to identify trends in Mobile Learning in Mathematics Education (MLME) research has gained considerable momentum. This method, which employs quantitative analyses of academic literature, allows researchers to map the evolution and direction of MLME studies over time. By analyzing publication patterns, citation records, and other bibliometric indicators, scholars can identify shifting dynamics and focal areas within the field. This approach reveals prevailing themes, significant works, and emerging research directions, offering a comprehensive view of the MLME research landscape. While numerous studies have utilized bibliometric techniques in MLME, a deeper examination reveals limitations that present opportunities for further exploration.

Additionally, existing MLME studies often concentrate on specific themes, such as student engagement, cognitive development, and collaborative learning. For instance, Irwanto et al. (2023) investigated MLME's role in fostering collaboration skills in higher education, highlighting its impact on analytical abilities within group learning contexts. However, this emphasis on higher education limits its applicability to K-12 settings, where foundational mathematics skills are critical. Studies like Osman and Napeah (2021) emphasize the importance of engagement but do not address MLME's support for diverse learning profiles. This research broadens these themes to encompass MLME's role across varied educational levels and settings.

Further, previous studies have often focused on specific regions or exclusively on English-language publications, limiting the inclusivity of non-English contributions and regional insights. For example, Churiyaha et al. (2022) focused predominantly on Indonesian outputs, while others have limited their analyses to English-language sources. To address these limitations, this study adopts a global perspective, examining MLME research without language restrictions to provide a more inclusive understanding of MLME's impact across different educational and cultural contexts.

Moreover, the temporal scope of existing MLME bibliometric studies varies considerably, affecting the continuity and comprehensiveness of insights into research progress. For example, Kaya and Kutluca (2023) observed a surge in MLME publications during the COVID-19 pandemic, particularly from 2020 to 2021, as remote learning became essential. However, some studies lack a clearly defined temporal scope, which limits their ability to provide a longitudinal perspective. This study examines publications from 2020 to 2025, offering a recent and contemporary perspective that accounts for technological advancements and shifts in educational practices prompted by the pandemic.

By addressing these identified gaps, this study seeks to provide a bibliometric analysis of MLME that is more comprehensive, globally inclusive, and attentive to thematic and temporal factors. This approach aims to illuminate the current state of MLME research, map its development, and establish a foundation for future inquiry. Through a rigorous selection process, a dataset of 74 documents has been compiled, ensuring a globally representative, thorough, and temporally inclusive examination of the MLME field. The goals of this study are to navigate the MLME landscape, identify emerging trends, highlight key contributors, and uncover critical themes essential for advancing MLME research.

Research Questions

This paper presents a bibliometric analysis of M-learning in mathematics education by focusing on six main research questions (RQs):

RQ 1: What is the current landscape of M-learning in mathematics education research?

RQ 2: What emerging trends are observable in M-learning in mathematics education publications?

RQ 3: Which journals and publications serve as epicentres for groundbreaking M-learning in mathematics education studies?

RQ 4: What landmark papers have shaped the discourse and direction of M-learning in mathematics education research?

RQ 5: Which key players authors, institutions, and countries are driving advancements in M-learning in mathematics education research?

RQ 6: What pivotal research themes underpin the development and growth of the M-learning in mathematics education field?

The comprehensive nature of this study provides an opportunity to thoroughly understand the scope of research on M-learning in mathematics education. By employing bibliometric and network analysis techniques, this study establishes a deep understanding of the scholarly landscape, core themes, and clusters within this domain. The insights gained are crucial for guiding the development of more effective educational practices that leverage M-learning, aligning with the continuously evolving technological and educational standards. Ultimately, this study aims to map the complex landscape of M-learning in mathematics education. Through meticulous analysis, it provides a clear overview of the field's historical and current state, laying the foundation for future advancements. This endeavor is directed towards enhancing the effectiveness and fostering innovation in educational systems through the integration of M-learning.

METHOD

This study employed data sourced from the Scopus database as of October 18, 2024. The collected data encompassed a range of variables, such as document types, source types, languages, subject areas, publication trends, average authorship per document, institutional contributions, publication distribution by country, and prominent keywords, among other aspects. Many prior studies on MLME have relied on single-database sources, such as Scopus, potentially narrowing the scope of analysis. This study, therefore, acknowledging the value of integrating multiple databases such as Web of Science and Google Scholar in future research to achieve a more comprehensive analysis.

Search Strategy

The review adopted the modified PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines for conducting systematic reviews of (Moher et al., 2009). The search string ("Mobile Learning" OR "M-Learning") AND "Math*" AND ("Educat*" OR "Learn*" OR "Teach*" OR "Pedagog*") was entered into the Scopus search engine. Then, subject filters were applied. The scope and coverage in this study were based on search field, time frame, source type, and document type to exclude irrelevant papers. This search yielded 556 documents (see Figure 1). After scanning the abstracts of all documents in the list, further exclusions were made based on topical relevance. After the screening of documents had been completed, 74 documents on M-learning in mathematics education remained in the final database.

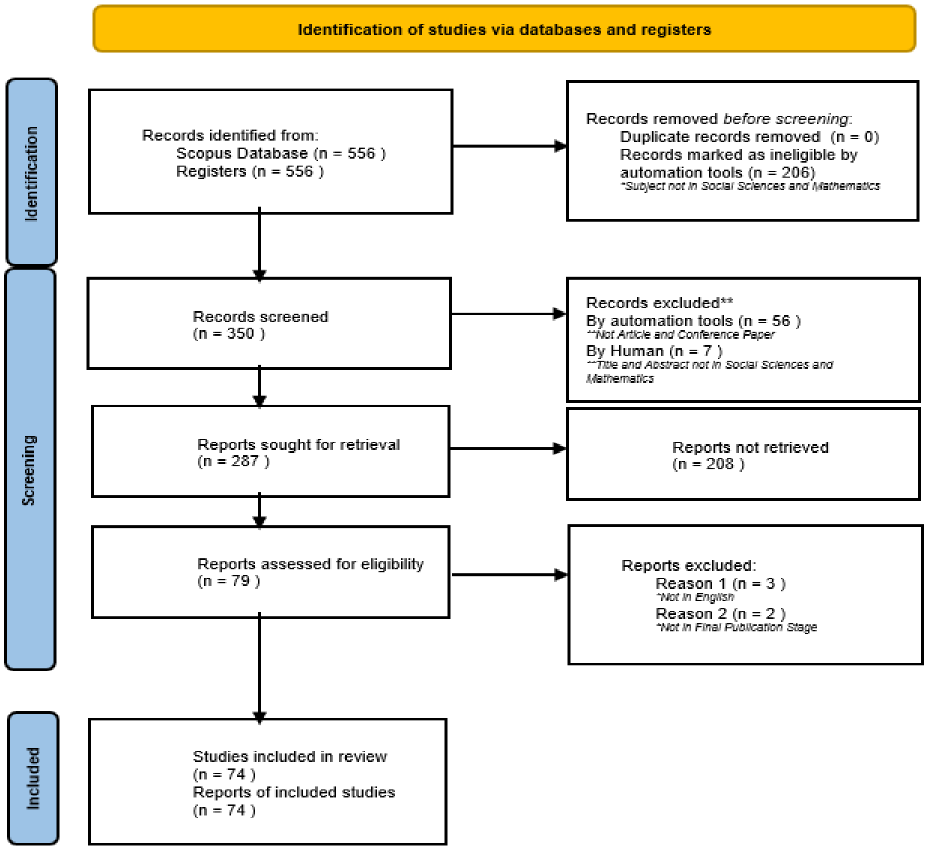

Figure 1
Flow diagram of the search strategy

Data Cleaning

Data cleaning and harmonisation are essential for ensuring accuracy and reliability in bibliometric analysis. This study employed OpenRefine and biblioMagika® (Ahmi, 2023), tools specifically designed to refine and align inconsistent data, particularly for author names, affiliations, keywords, and other bibliographic details. These tools proved invaluable for achieving data precision and consistency, especially given the diversity of research outputs and potential inconsistencies within the dataset. The process began by downloading data in CSV format, with selected files marked for refinement. Specific columns such as keywords, authors' names, and affiliations were targeted for adjustments using various functions within the clustering tools. Advanced bibliometric assessments were conducted with biblioMagika®, measuring Total Publications (TP), Number of Contributing Authors (NCA), Number of Cited Publications (NCP), Total Citations (TC), Citations per Publication (C/P), Citations per Cited Publication (C/CP), Citations per Author (C/A), Authors per Publication (A/P), Citations per Year (C/Y), Citable Year, h-index, g-index, m-index, and Citation Sum within the h-Core, across categories such as publication year, source titles, authors, institutions, and countries. Furthermore, biblioMagika® was instrumental in identifying missing data, enabling manual completion of these gaps, which facilitated the cleaning and harmonisation processes. By utilising these sophisticated tools, researchers were able to safeguard the integrity of their analyses and the reliability of their results. Overall, data harmonisation and cleaning enhanced the clarity and robustness of the research dataset, establishing it as a solid foundation for exploring the complexities of M-Learning in mathematics education.

Data Analysis

The data analysis was structured to directly address the research questions. The authors' approach involved mapping the current landscape of M-learning research in mathematics education, focusing on document types, source categories, languages, subject areas, and citation metrics. The findings were presented across several criteria, such as annual publication volume, contributions from leading authors, prominent institutions, key countries, and influential source titles, highlighting major contributors and trends within the field. To assess the impact and significance of the publications, bibliometric indicators were used, including total publications, number of cited papers, total citations, citations per publication, citations per cited publication, h-index, g-index, m-index, and total citation count within the h-core. Additionally, to uncover dominant themes and concepts in this field, the authors applied methods like co-occurrence network analysis, thematic mapping, and factorial analysis to visualise the authors' keywords. These visualisations allowed for the identification of topic clusters, detection of patterns, and exploration of connections among various research subfields.

Tools

The study utilized a range of tools to perform a comprehensive bibliometric analysis. Microsoft Excel was used for initial data cleaning and organization, while biblioMagika® streamlined the cleaning, harmonization, and standardization of data on authors' affiliations and countries. OpenRefine was applied specifically to harmonize and clean data for authors' keywords. Once the data was prepared, VOSviewer generated informative visual representations of the research findings, with Mendeley serving as the reference manager. This combination of tools and techniques enabled a thorough and rigorous examination of the field of M-learning in mathematics education.

FINDINGS

In the upcoming results section, the authors will present an in-depth examination of the research landscape for M-learning in mathematics education. This detailed analysis will address the research questions (RQs), yielding a deep understanding of the field. Through this focused analysis, the authors are committed to delivering a detailed and insightful overview of the M-learning in mathematics education domain, contributing valuable knowledge for scholars, practitioners, and decision-makers.

RQ1: Current Landscape of M-learning in Mathematics Education Research

To address the initial research question, which aims to map the current state of M-learning in mathematics education research, the authors will analyze the distribution of publications across multiple factors, including document type, source type, languages, and subject areas. Additionally, citation metrics will be assessed to gauge the impact and significance of these contributions within the field of M-learning in mathematics education. The data were first organized by document type, encompassing a range of formats such as articles, conference papers, book chapters, and review articles. Conference papers often present research findings shared at scholarly conferences, with some subsequently published in proceedings or as book chapters.

Through an extensive analysis covering the period from 2007 to 2024, a comprehensive dataset in Table 1 highlights significant academic contributions, totaling 74 publications that demonstrate a robust research trajectory. This body of work involves a wide network of 246 contributing authors, underscoring the collaborative nature of scholarly research. The count of 64 cited papers points to the substantial reach and influence of these contributions within the academic community. An impressive total of 1003 citations further reinforce the impact of this research over the 18 citable years. This research collection has garnered an average of 13.55 citations per paper, indicating consistent recognition across the published works. Furthermore, for cited papers exclusively, the average citation per paper rises to 15.67, reflecting concentrated acknowledgment by peers and highlighting the higher impact of those works that have been referenced. These metrics collectively illustrate not only the volume of research output but also emphasize the quality and influence of the work produced, providing a comprehensive view of the academic footprint of this body of scholarly literature.

Table 1
Citation metric

Main Information	Data
Publication Years	2007 - 2024
Total Publications	74
Citable Year	18
Number of Contributing Authors	246
Number of Cited Papers	64
Total Citations	1,003
Citation per Paper	13.55
Citation per Cited Paper	15.67
Citation per Year	59.00
Citation per Author	4.08
Author per Paper	3.32
Citation sum within h-Core	958
h-index	18
g-index	29
m-index	1.000

RQ2: Publication Trends of M-learning in Mathematics Education Research

To address the second research question, the authors traced the developmental trajectory of this growing field. The earliest recorded publication in 2007 marks the beginning of research in M-learning in mathematics education, which has steadily increased over time. By 2023, there were 12 publications with 23 total citations, indicating a steady growth in interest (as shown in Figure 2 and Table 2). The visualisation of total publications and citations demonstrates an upward trend, punctuated by notable spikes, particularly in 2016, where 215 citations were recorded alongside 6 publications. The line graph mirrors this rise in citations, signifying the increasing scholarly impact of M-learning in mathematics education research over the years.

Concurrent with the rise in total publications, there has also been a significant increase in the Number of Contributing Authors (NCA), reaching 38 in 2023, reflecting a growing and collaborative research community. This progression highlights the multidisciplinary nature of M-learning in mathematics education, which integrates mathematics education, technology and mobile learning. The increasing collaboration and contributions from a diverse range of authors suggest that the field is gaining broader recognition and academic significance, positioning itself as an integral part of modern educational research.

In terms of impact, the h-index and g-index values, as shown in Table 2, reflect the rising prominence of this field. The h-index reached 46, while the g-index stood at 58, indicating a substantial number of highly cited papers. The m-index shows some fluctuations over the years, peaking at 1.5 in 2021, indicating a high rate of influential publications during that period. These metrics underscore the increasing relevance of M-learning in mathematics education research, though the variability in citation rates points to evolving scholarly impact. Further investigation is warranted to understand the causes behind these fluctuations, particularly in relation to citation behaviours and the overall quality of publications within the domain. These patterns highlight the increasingly crucial role of M-learning in mathematics education as an interdisciplinary field advancing knowledge and innovation.

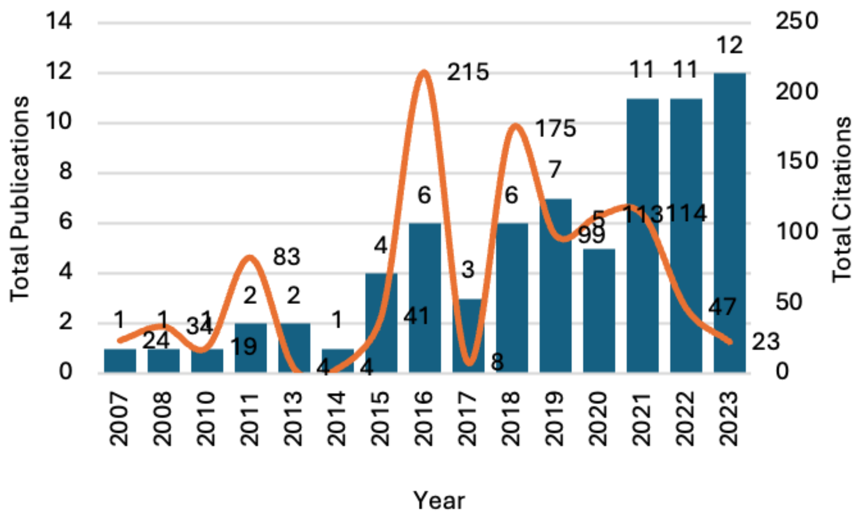

Figure 2
Total publications and citations by year (Excluding the year 2024 as data is only available up to 19 October 2024)

Table 2
Publication by year

Year	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
2007	1	5	1	24	24.00	24.00	1	1	0.056
2008	1	3	1	34	34.00	34.00	1	1	0.059
2010	1	3	1	19	19.00	19.00	1	1	0.067
2011	2	7	2	83	41.50	41.50	2	2	0.143
2013	2	6	1	4	2.00	4.00	1	2	0.083
2014	1	1	1	4	4.00	4.00	1	1	0.091
2015	4	11	4	41	10.25	10.25	4	4	0.400
2016	6	18	6	215	35.83	35.83	5	6	0.556
2017	3	13	2	8	2.67	4.00	2	2	0.250
2018	6	13	6	175	29.17	29.17	6	6	0.857
2019	7	23	7	99	14.14	14.14	5	7	0.833
2020	5	15	5	113	22.60	22.60	5	5	1.000
2021	11	41	11	114	10.36	10.36	6	10	1.500
2022	11	45	9	47	4.27	5.22	4	6	1.333
2023	12	38	7	23	1.92	3.29	2	4	1.000
Grand Total	73	242	64	1003	13.55	15.67	46	58	7.371

Notes: TP = total number of publications; NCA = number of contributing authors; NCP = number of cited publications; TC = total citations; C/P = average citations per publication; C/CP = average citations per cited publication; h = h-index; g = g-index; m = m-index.
* Publication data for the year 2024 is only up until 18 October 2024

RQ3: Source Title of M-learning in Mathematics Education Research

Table 3 identifies the leading source titles actively contributing to M-learning in mathematics education, particularly those with two or more publications. The South African Journal of Education leads with a total publication count (TP) of 3 and a total citation count (TC) of 41, underscoring its substantial impact. Its h-index of 3 reflects its prominent role in M-learning research. The Lecture Notes in Computer Science, which includes subseries on Artificial Intelligence and Bioinformatics, demonstrates interdisciplinary reach with a TC of 14 and a C/P (average citations per publication) of 4.67, indicating room for increased influence.

Other notable contributors include the International Journal of Emerging Technologies in Learning and the International Journal of Engineering Pedagogy, each with two publications and moderate citation performances. Education Sciences stands out with a TC of 43 and an h-index of 2, achieving a high C/P of 21.50, asserting its prominence. The g-index and m-index metrics further illuminate the research impact of these journals. For example, the European Journal of Educational Research and Sustainability (Switzerland) show robust g-index values and favorable m-indices, indicating consistent citation activity.

Table 3
Most active source titles that published two (2) or more documents

Source Title	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
South African Journal of Education	3	9	3	41	13.67	13.67	3	3	0.300
Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	3	8	2	14	4.67	7.00	2	3	0.167
International Journal of Emerging Technologies in Learning	2	6	2	7	3.50	3.50	1	2	0.250
International Journal of Engineering Pedagogy	2	6	2	24	12.00	12.00	2	2	0.286
Education Sciences	2	7	2	43	21.50	21.50	2	2	0.500
Frontiers in Education	2	9	2	12	6.00	6.00	1	2	0.333
Infinity Journal	2	7	1	5	2.50	5.00	1	2	0.167
European Journal of Educational Research	2	6	2	9	4.50	4.50	2	2	0.667
Sustainability (Switzerland)	2	8	2	8	4.00	4.00	2	2	0.667
Eurasia Journal of Mathematics, Science and Technology Education	2	11	2	29	14.50	14.50	2	2	0.333

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

RQ4: Highly Cited Documents of M-learning in Mathematics Education Research

Table 4 highlights the top five highly cited articles in the field of M-learning in mathematics education, showcasing influential works that have made significant contributions to this area. Leading the list is Borba et al. (2016), whose research on blended learning, e-learning, and M-learning in mathematics education has received 163 citations, with an impressive average of 18.11 citations per year. This study underscores the importance of integrating various digital learning approaches in mathematics, establishing itself as a foundational piece within the field.

Following this is the article by Fabian et al. (2018), which examines the use of mobile technologies to enhance student attitudes and achievement in mathematics. Garnering 62 citations with an average of 8.86 citations per year, this study highlights the impact of mobile technology on educational outcomes. Another significant work by Cook et al. (2011) explores the concept of ubiquitous mobility in mobile learning, particularly within mathematics, and has been cited 54 times, emphasizing its role in creating flexible learning environments through mobile phones.

Other notable works include Miller (2018), which focuses on developing numeracy skills using interactive technology in a play-based learning setting, and Hwang & Fu (2020), which analyzes advancements and trends in smart learning environments in the mobile era. These articles collectively reflect the increasing body of research demonstrating the potential and effectiveness of M-learning in mathematics education, illustrating the critical role it plays in modern educational practices.

Table 4
Top five (5) highly cited articles

No.	Author(s)	Title	TC	C/Y
1	Borba et al. (2016)	Blended learning, e-learning and mobile learning in mathematics education	163	18.11
2	Fabian et al. (2018)	Using mobile technologies for mathematics: effects on student attitudes and achievement	62	8.86
3	Cook et al. (2011)	Ubiquitous mobility with mobile phones: A cultural ecology for mobile learning	54	3.86
4	Miller (2018)	Developing numeracy skills using interactive technology in a play-based learning environment	53	7.57
5	Hwang & Fu (2020)	Advancement and research trends of smart learning environments in the mobile era	49	9.80

RQ5: Publication by Authors, Instituitions and Countries of M-learning in Mathematics Education Research

Table 5 presents the most productive authors in the field of M-learning in mathematics education, identifying those with more than three publications. Leading this group is Matthias Ludwig from Goethe University Frankfurt, Germany, with a total of 4 publications and 4 cited publications, resulting in 75 total citations. Ludwig's work yields an average of 18.75 citations per publication, with an h-index of 3, g-index of 4, and an m-index of 0.500, underscoring his substantial academic influence. Following Ludwig are Maja Matetic and Petar Juric, both from the University of Rijeka, Croatia, with 3 publications each and a total of 14 citations, achieving an average of 4.67 citations per publication. Both authors maintain an h-index of 2, a g-index of 3, and an m-index of 0.500, indicating their significant contributions within Croatian M-learning research.

From the University of Johannesburg, South Africa, Garth Spencer-Smith and Nicky Roberts each have 3 publications with 21 total citations, averaging 7.00 citations per publication. Both authors hold an h-index of 3 and a g-index of 3, with an m-index of 0.300, reflecting their impactful contributions to the South African research context in M-learning. Marija Bakaric, also from the University of Rijeka, has 3 publications and 14 citations, aligning closely with her Croatian colleagues in citation metrics. Collectively, these authors demonstrate a strong international and collaborative research presence in M-learning in mathematics education, underscoring the interdisciplinary impact of this field.

Table 5
Most productive authors that published more than three (3) documents

Full Name	Current Affiliation	Country	TP	NCP	TC	C/P	C/CP	h	g	m
Ludwig, Matthias	Goethe University Frankfurt	Germany	4	4	75	18.75	18.75	3	4	0.500
Matetic, Maja	University of Rijeka	Croatia	3	3	14	4.67	4.67	2	3	0.500
Juric, Petar	University of Rijeka	Croatia	3	3	14	4.67	4.67	2	3	0.500
Spencer-Smith, Garth	University of Johannesburg	South Africa	3	3	21	7.00	7.00	3	3	0.300
Bakaric, Marija Brkic	University of Rijeka	Croatia	3	3	14	4.67	4.67	2	3	0.500
Roberts, Nicky	University of Johannesburg	South Africa	3	3	21	7.00	7.00	3	3	0.300

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

Other than that, Table 6 presents the most productive institutions in the field of M-learning in mathematics education, listing those with at least six publications. Leading the table are the University of Rijeka in Croatia, Ho Chi Minh City University of Education in Vietnam, and Goethe University Frankfurt in Germany, each with a total of 9 publications. Among these, Goethe University Frankfurt demonstrates significant citation impact, with 92 total citations and an average of 10.22 citations per publication, supported by an h-index of 5 and a g-index of 9.

Utah State University in the United States stands out with 8 publications and a substantial total of 176 citations, achieving an average of 22.00 citations per publication. Its h-index of 8 and g-index of 8 reflect a notable influence within M-learning research in mathematics education. The University of the Aegean in Greece, with 6 publications, follows with a total of 66 citations and an average of 11.00 citations per publication, underscoring its consistent contribution. Collectively, the citation metrics, including h-index and g-index values, illustrate the leading role these institutions play in advancing research and knowledge in this domain, demonstrating a wide-reaching and interdisciplinary academic influence.

Table 6
Most productive institutions with a minimum of six (6) publications

Institution Name	Country	TP	NCA	NCP	TC	C/P	C/CP	h	g	m
University of Rijeka	Croatia	9	NR	9	42	4.67	4.67	6	6	1.500
Ho Chi Minh City University of Education	Viet Nam	9	NR	9	18	2.00	2.00	2	4	1.000
Goethe University Frankfurt	Germany	9	NR	9	92	10.22	10.22	5	9	0.833
Utah State University	United States	8	NR	8	176	22.00	22.00	8	8	2.000
University of the Aegean	Greece	6	NR	6	66	11.00	11.00	5	6	0.714

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

Finally, Figure 3 and Table 7 provide an overview of the global research contributions in M-learning in mathematics education, focusing on countries that have contributed nine or more publications. Indonesia leads the field with 32 publications and a total citation count of 350, demonstrating a strong impact with an h-index of 11 and an average of 10.94 citations per publication. This reflects Indonesia's prominent role and influence in M-learning research, supported by a high m-index of 1.833. The United States follows closely with 20 publications and a substantial total of 335 citations. The United States achieves an h-index of 12 and an average citation per publication of 16.25, signifying its impactful contributions in this research domain. Similarly, Germany contributes 17 publications with a total of 161 citations, achieving an h-index of 10 and an average of 9.47 citations per publication, highlighting its consistent scholarly presence.

Vietnam and Greece are also notable contributors with 15 and 12 publications, respectively. Vietnam has accumulated 96 citations with an average of 6.40 citations per publication, while Greece has garnered 88 citations, averaging 7.33 citations per paper. Both countries demonstrate growing influence, as evidenced by their respective h-indices of 6 and 5. South Africa, Canada, and Croatia each bring significant research activity, with 11, 9, and 9 publications, respectively. Canada, with a high citation count of 250 and an average of 27.78 citations per publication, shows a particularly strong impact. Croatia achieves an impressive average of 4.67 citations per publication, with an h-index of 6, reflecting its focused contributions within Europe. These data, including h-index, g-index, and m-index values, underscore the diverse and international scope of research in M-learning in Mathematics Education.

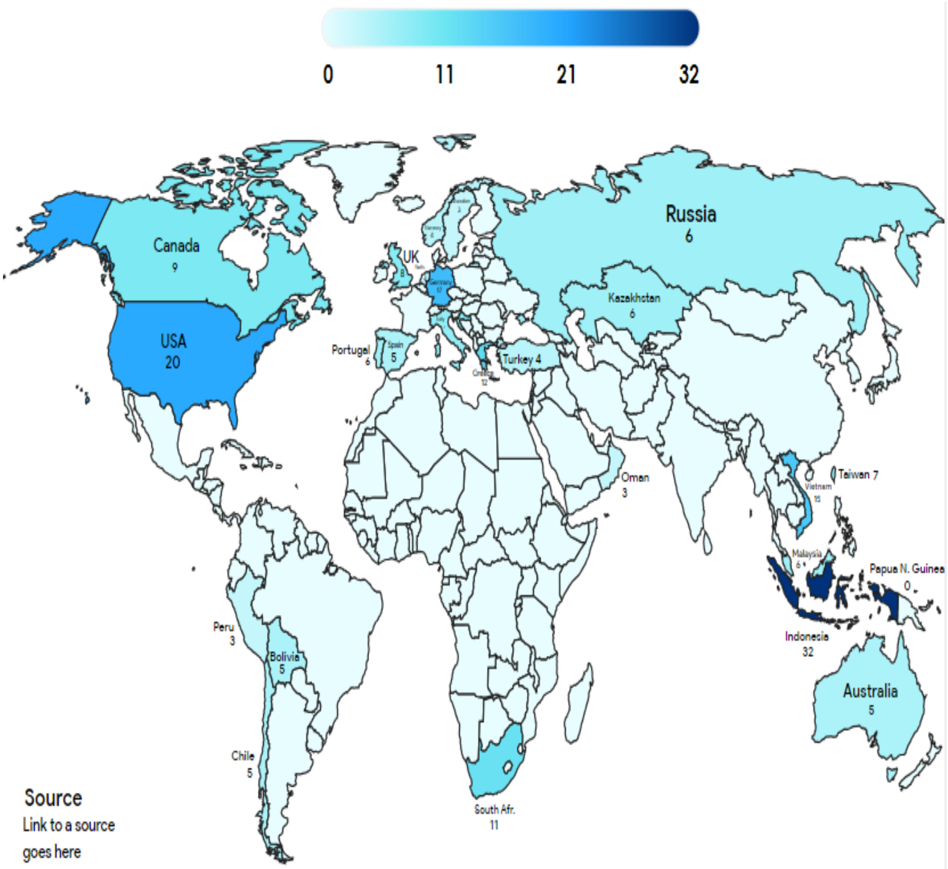

Figure 3
Visualisation of global distribution of M-learning in mathematics education research

Table 7
Countries that contributed nine (9) or more publications

Country	TP	NCP	TC	C/P	C/CP	h	g	m
Indonesia	32	22	350	10.94	15.91	11	18	1.833
United States	20	17	325	16.25	19.12	12	18	0.857
Germany	17	15	161	9.47	10.73	5	12	0.357
Viet Nam	15	15	96	6.40	6.40	6	9	1.000
Greece	12	12	88	7.33	7.33	5	9	0.625
South Africa	11	11	258	23.45	23.45	8	11	0.800
Canada	9	9	250	27.78	27.78	5	9	0.500
Croatia	9	9	42	4.67	4.67	6	6	1.500

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

RQ6: Co-occurrence Analysis of M-learning in Mathematics Education Research

The co-occurrence network in Figure 4 offers a detailed analysis of prominent research Themes and their interrelationships within M-learning in the context of mathematics education. This network, based on keywords with a minimum of 10 occurrences, provides a comprehensive view of how key themes intersect and inform one another. At the center of the network, “mobile learning” and “mathematics education” emerge as dominant nodes, signifying their foundational role in this field. The proximity of these nodes illustrates the close connection between mobile learning technologies and their specific applications in mathematics education. Surrounding these central themes, several clusters represent distinct research foci within M-learning studies.

One notable cluster is defined by the theme “technology-enhanced learning,” which encompasses research integrating digital and mobile tools to enrich mathematics learning environments. This theme reflects a transition from conventional teaching methods toward more interactive, dynamic, and accessible approaches. This shift is especially relevant in mathematics, where active student engagement can be difficult to achieve in traditional settings. Adjacent to this, another cluster is centered on “game-based learning,” a theme that has gained traction as researchers investigate gamification’s role in increasing student engagement and motivation in M-learning contexts. By embedding mathematical concepts within game structures, this approach seeks to make mathematics more engaging, particularly for younger learners.

The cluster focused on “mathematical conceptual knowledge” explores the cognitive dimensions of M-learning, specifically how mobile applications can support students’ conceptual understanding of mathematics. This theme underscores the importance of fostering a deeper comprehension of mathematical principles, beyond procedural skills, through mobile platforms. Additional thematic areas, including “learning activities” and “engineering education,” indicate the adaptability of M-learning across diverse educational fields, highlighting interdisciplinary interest. The network also reveals an emerging focus on “COVID-19,” reflecting how the pandemic has accelerated the adoption of mobile learning technologies in mathematics education as institutions adapted to remote learning requirements.

In summary, the co-occurrence network illustrated in Figure 5 maps out the interconnected research themes within M-learning in mathematics education. Each cluster reflects a unique dimension of this field, collectively highlighting the breadth and depth of current research pursuits. This network not only captures prevailing research priorities but also serves as a valuable framework for guiding future inquiries, emphasizing the transformative role of mobile learning technologies in mathematics education.

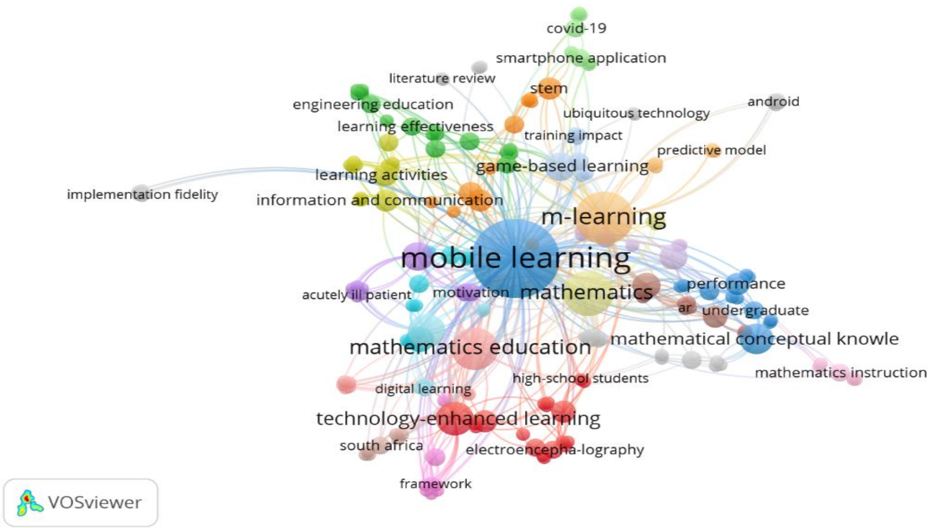

Figure 4
Co-occurrence network of the author's keywords with at least 10 Occurrences

DISCUSSION

This study provides a comprehensive bibliometric analysis of M-learning in mathematics education, examining the field's development, regional contributions, institutional influence, and key thematic areas. Covering publications from 2007 to 2024, the dataset reveals rapid growth in this research area, especially from 2020 onward. This trend was likely driven by the COVID-19 pandemic, which led to a global shift toward remote learning solutions. The surge aligns with findings from Tang et al. (2023), who observed that crises can accelerate the adoption of digital learning technologies. This pattern is consistent with broader trends in educational research, where external challenges reshape instructional priorities and promote swift innovation in teaching methods.

The analysis of contributions by country shows that Indonesia, the United States, and Germany are leading contributors to M-learning research in mathematics education. Indonesia, with 32 publications and an h-index of 11, reflects a strong emphasis on digital education across Southeast Asia, establishing its role in advancing digital pedagogies. The United States follows closely, benefiting from a robust research infrastructure and technological innovation often supported by strategic funding in educational technology. Germany, with 17 publications, demonstrates focused academic interest in educational technology and mathematics education. These countries' prominence aligns with global educational priorities that view technology as essential for enhancing learning outcomes in foundational subjects such as mathematics.

Institutions that play a key role in this field include the University of Rijeka, Goethe University Frankfurt, and Utah State University, each making significant contributions in terms of research volume and impact. Utah State University is notable for its high average citations per paper, which highlights the influence of its research on applying M-learning in mathematics education. High-impact institutions emphasize the importance of interdisciplinary collaboration in advancing M-learning, as noted by Fabian et al. (2018), who underscored the role of institutions in educational innovation. The global spread of contributing institutions reflects a widespread interest and investment in M-learning.

A thematic analysis, visualized through a network of co-occurring keywords, identifies core themes such as "mobile learning," "mathematics education," "technology-enhanced learning," and "game-based learning." This range of themes illustrates the multi-dimensional nature of M-learning, intersecting with various pedagogical approaches to enhance student engagement, motivation, and performance. The emphasis on "game-based learning" aligns with Qashou (2021), who highlighted the benefits of interactive elements for engaging students in mathematics. The focus on "COVID-19" as a theme underscores the pandemic-driven shift toward digital and mobile learning solutions, as noted by Güler et al. (2021) and Sharafeeva (2022).

Despite these advancements, integrating M-learning into mathematics education faces challenges. Accessibility remains a critical issue, especially in under-resourced regions where limited device availability and internet connectivity hinder adoption, as noted by Saritas (2022). Additionally, aligning M-learning with standard mathematics curricula and providing specialized training for teachers poses further challenges. Effective use of digital tools depends on teachers' ability to apply them in pedagogically sound ways, as highlighted by Zakaria et al. (2023).

CONCLUSION

In conclusion, this bibliometric analysis provides a comprehensive overview of M-learning in mathematics education, revealing the field's rapid growth, diverse regional contributions, and thematic richness. The notable contributions from countries like Indonesia, the United States, and Germany, as well as key institutions, underscore the global commitment to enhancing mathematics education through mobile learning technologies. Central themes identified in this analysis range from game-based learning to technology-enhanced instruction demonstrate the pedagogical versatility of M-learning in addressing various educational challenges. The study also highlights key challenges such as accessibility, curriculum alignment, and teacher preparedness, which must be addressed to maximize M-learning's potential in mathematics education. Moving forward, policy initiatives that promote equitable access to digital tools, support teacher training, and ensure curricular alignment will be critical for advancing M-Learning integration in mathematics education. This study provides a foundation for future research, offering insights that can guide strategic investments, foster collaborative research, and enhance the practical application of M-learning across diverse educational contexts. Through a balanced approach that considers technological, pedagogical, and accessibility dimensions, M-learning has the potential to create more inclusive, effective, and flexible learning environments in mathematics education globally.

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