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Publication Trends on Mobile Learning in Science Education

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Abstract: *Mobile learning is gaining popularity in science classes because it has the potential to increase student engagement and learning. This bibliometric analysis examines the trends in mobile learning and science education publications. Scopus and Web of Science (WoS) datasets were used in this bibliometric analysis. ScientoPy was employed to analyse the data obtained using keywords ("mobile learning" OR "m-learning") AND ("science education" OR "science learning" OR "science teaching" OR "science"). The keywords "Mobile learning", "e-learning", "mobile devices", "gamification," and "higher education" are the top five keywords used in previous publications. With 32 publications, the most productive institution is the National Taiwan University of Science and Technology. The top three source titles are Computers & Education, Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Bioinformatics), and the International Journal of Mobile Learning and Organization. The study's results give an overview of how mobile learning in science education has changed and can guide future research in this field. This bibliometric analysis also illustrates the current research on mobile learning in science education. The results suggest that mobile learning could be an excellent way to get students more interested in science and help them learn more. Inevitably, this bibliometric review of mobile learning in education only scratches the surface of a vast body of literature, with some parts of the theme have been disregarded.*

Keywords: Mobile learning, science education, bibliometrics

1. Introduction

Mobile learning is a fast-expanding domain of educational technology with the potential to transform how science is taught and learned in classrooms. Mobile learning or m-learning is "the delivery of learning, education or instruction using mobile technology" (Bates, 2015). Mobile learning is gaining popularity in education because it promises to provide learners the flexibility and convenience of learning "anytime" and "anywhere". Mobile learning is an effective tool for science education, as it can provide students with various learning experiences (Coelho et al., 2023). As such, mobile devices can facilitate field studies, online simulations, and interactive multimedia activities (Klopfer and Squire, 2008). Additionally, Chung et al. (2019) and Hutagaol et al. (2022) corroborated that mobile learning allows students to engage in collaborative learning activities and utilise real-world data to inform their learning.

Mobile learning provides unique opportunities for science learning that are not available in more traditional environments. A likely reason is that mobile technology can transform

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traditional education into a more interactive, engaging, and personalised learning experience (Alfalah, 2023). In recent years, mobile technology has become increasingly accessible and affordable, making it an ideal platform for science education (Criollo-C et al., 2021; Moro et al., 2021). In discussing mobile technology, it is appealing that the interaction between people and devices or gadgets is mutually advantageous, which is considered a symbiotic nexus. The existence of modern gadgets today, such as smartphones, tablets, and laptop computers, are all transportable devices that ease people in completing their daily routines and specific tasks (Abdullah and Othman, 2022). However, an internet connection is considerably required to utilise those gadgets' fully functioning.

In the educational context, it is noted that mobile technology is one of the reform endeavours in making the teaching and learning process pleasurable and flexible (Qashou, 2021). Also, mobile technology encourages students to enhance their fathoming of complex philosophies or thoughts in science education (Bernacki et al., 2020). Complex ideas in science are likely necessary for dealing with numerous kinds of representation, such as diagrams, graphs, and equations (Ainsworth, 2008), which might provide exclusive advantages using educational apps. With mobile devices, students can access the internet, educational apps, and virtual simulations to explore and learn about scientific concepts (Hutagaol et al., 2022). This necessitated that students always learn flexibly and utilise mobile devices to attract curiosity in completing their coursework.

Since the 1980s, incorporating digital technologies into teaching and learning has been a recurring issue in the Educational Technology literature (Pedro et al., 2018). This indirectly depicted that the education system has changed radically, whereby mobile technology has been taken by storm remotely on digital platforms. In science education, mobile technology in the classroom or laboratory settings has made mobile and ubiquitous learning pedagogy more critical (Dewi et al., 2022). This has, in turn, required teachers to have technological pedagogical and subject knowledge (TPACK) (Srisawasdi et al., 2018). Costs, lack of information technology (IT) support, lack of faculty acceptance, lack of structured assignments designed to encourage the implementation of mobile devices and limitations regarding their use in the teaching and learning process must be considered when expanding the use of mobile technology (Raman, 2015).

While mobile learning can provide many benefits, there are also potential challenges. For mobile learning to be more effective, its management must be improved, and the controlling party must analyse the level of student involvement with learning (Chavoshi and Hamidi, 2019). In the absence of momentum toward buoyant agility, the incapacity to implement mobile learning in science education is growing pervasive and corroding the efficacy of scientific skills and technology embraced by students. Also, mobile devices can be expensive to purchase, maintain, and replace, which can be a barrier to limited resources. In addition, the government should offer students free roaming services. Mobile learning is here to stay, and its use is growing due to the current technological advancements; therefore, improvements should be made continuously so that science subjects' teaching and learning processes evolve, attracting students' interest in this subject.

Mobile learning in science education can be an effective and engaging way to teach students. However, the successful implementation of mobile learning in science education depends on the availability of resources and the quality of content, both of which can be preserved by government initiatives. Government funding can be used to purchase the necessary hardware, software, and content to ensure quality learning experiences (Rasmitadila et al., 2020).

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Government initiatives can also provide teachers with professional development to help them utilise mobile learning effectively (Abd Samad et al., 2021). Also, government-funded research can provide valuable insight into the effectiveness of mobile learning in science education (Lai, 2020).

Mobile learning has become increasingly popular in the educational sector due to the advancement of technology and its increasing accessibility. Technology supporting learning has been widely adopted in formal and informal learning environments (Viberg et al., 2021). Bibliometric analysis was performed to analyse co-citation and research clusters in mobile learning to support successful learning experiences for students (Khan and Gupta, 2022). Also, the bibliometric analysis of mobile learning has identified the most studied topics, the most used terms, and the most cited journals in vocational high schools (Churiyah et al., 2022). According to the results of this analysis, this review can serve as a springboard for additional studies on mobile learning in the context of vocational high school instruction. These two studies both demonstrate the potential of bibliometric analysis to provide insights into the development of mobile learning in the educational sector.

Nevertheless, a bibliometric analysis of mobile learning in science education is limited. Mobile learning has been gaining popularity in recent years due to its potential to increase the effectiveness of science education. Bibliometric analysis is a valuable tool to analyse the trends and patterns in the literature related to mobile learning in science education. This study aims to analyse a bibliometric concerning scholarly literature focusing on mobile learning in science education, assess the trends and patterns of research in this area, and identify potential gaps in the research.

2. Methodology

2.1 Bibliometric Overview

Bibliometrics is an assessment technique used to measure the impact of published material and the relative importance of research topics in a field (Abdullah, 2022). It is an essential tool for assessing the quality and relevance of published research and is increasingly used by researchers, librarians, and funding agencies. The bibliometric analysis also can be a form of content analysis that uses quantitative methods to examine and interpret published literature in different fields (Abdullah et al., 2022). It is used to understand a field's development, measure a publication or an author's impact, or identify the most influential authors and publications.

Furthermore, bibliometrics can measure the impact of individual authors, journals, and research topics and compare the productivity and impact of different institutions and countries (Abd Aziz et al., 2021). Nowadays, bibliometric analysis is valuable in assessing the impact of different publishing strategies, such as open-access publishing, and informing decisions about library collections. The most measurable aspect scrutinised by previous researchers on bibliometric analysis is that it can provide an overview of the state of research in a field, identify emerging trends and important research topics, and identify collaboration and geographical distribution patterns (Abdullah and Othman, 2022).

To utilise bibliometric measurement related to mobile learning in science education to its fullest extent, it is necessary to undertake the following steps. Using Scopus and WoS databases, the current study's research design followed the seven phases outlined in Table 1.

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Table 1: Seven Steps in Conducting Bibliometric Analysis

Step	Input	Clarification
1	Identify the research question	The research question for this bibliometric analysis focuses on mobile learning in science education
2	Select the search strategy	The search strategy combines keywords, subject terms, and Boolean operators to identify relevant literature
3	Select the databases	Scopus and WoS are the two databases to be used for this bibliometric analysis
4	Run the search	Use the search strategy to run and collect the results from the two databases
5	Analyse the data	Analyse the data by performing descriptive and inferential statistical analysis. Depending on the research question, this could include an analysis of the authors, journals, countries, keywords, citation counts, and other related metrics
6	Interpret the results	Interpret the results and draw conclusions based on the analysis
7	Write the report	Write a report summarising the findings and discussing the implications for mobile learning in science education

2.2 Identify the Research Question

Citation analysis and other bibliometric approaches can be used to analyse mobile learning in science education. It helps discover significant authors and organisations, monitors research trends and categorises the most referenced journals and papers. The purpose of the present bibliometric analysis is to address the following research questions:

1. What are the most often discussed topics in the published studies on mobile learning?
2. What are the most productive authors and institutions in the publications on mobile learning in science education?
3. What are the most productive source titles and cited articles on mobile learning in science education?
4. What are the most significant growth trends in research on mobile learning in science education?

2.3 Database Selection, Search Strategy, and Dataset Analysis

The search strategy for obtaining a list of publications on mobile learning in science education in the Scopus and Web of Science databases (WoS) includes a combination of related keywords. The keywords comprise mobile learning, m-learning, science education, science learning, science teaching and science. Additionally, the search includes the Boolean operators AND and OR to combine the keywords and expand the search results. The search strategy was completed on January 1, 2023, without filters such as languages, article types, and subject areas, but it covers scholarly works published until December 31, 2022. Table 2 provides the search strings and the number of publications on both databases.

This study utilised the Scopus and WoS databases for bibliometric analysis, as both databases were widely employed by previous researchers (Echchakoui, 2020). Scopus is a multidisciplinary database that contains peer-reviewed publications from science, technology, medicine, social sciences, and humanities. It covers over 22,000 titles from over 5,000 international publishers and is updated daily. WoS is a multidisciplinary database containing over 33,000 scholarly journals from over 8,000 publishers. It is updated monthly and covers various science, technology, medicine, social sciences, and arts and humanities topics.

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Table 2: The Search Strings in Scopus and WoS Databases

Database	Search Strings	Total Number of Publications for Search within Title-Abs-Key
Scopus	((“mobile learning” OR “m-learning”) AND (“science education” OR “science learning” OR “science teaching” OR “science”))	1311 document results
WoS	(“mobile learning” OR “m-learning”) AND (“science education” OR “science learning” OR “science teaching” OR “science”)	691 document results

Scopus and WoS are used to analyse citation counts, impact factors, h-index, and other metrics such as journal impact factor, article influence score, and journal citation reports (Abdullah and Sofyan, 2023). They both provide information on authors, institutions, and journals. The main differences between the two databases are the type of publications indexed, the update frequency, and the metrics used for analysis (Singh et al., 2021).

ScientoPy is used to analyse the list of publications in this study. Using ScientoPy, it is possible to perform data analysis by considering the metadata from the two databases. This provides bibliographic data such as authors, publication year, source title, and subject categories (Ruiz-Rosero et al., 2019). By tracking the increase in publications over a specified time, ScientoPy software can be used to identify publication trends (Abdullah and Sofyan, 2023). It can also be used to identify the most prolific authors and institutions in the field of mobile learning in science education and publications’ citations.

The downloaded dataset was first preprocessed by removing duplicates and merging the remaining data. ScientoPy was utilised to do these operations. Duplicates exclusion is the process of removing duplicate records from a data set. Data entry errors or other data inconsistencies can cause duplicate records. Duplicate records can lead to skewed results and incorrect conclusions when analysing the data. In ScientoPy, duplicate records are identified and removed during a preprocessing stage. This stage allows researchers to identify and remove duplicate records from a data set, ensuring accurate analysis results. Data Combination is combining multiple data sets into a single data set. This combines data sources into a single, unified data set that can be used for analysis. In ScientoPy, data combination is accomplished during a preprocessing stage. The data is combined into a single table, allowing users to access it quickly and easily analyse the data.

The preprocessed data outcomes are displayed in Table 3. After sorting based on the document types, there were 1868 datasets. After eliminating the duplicates, this study obtained 1453 reliable and valid datasets for the subsequent analysis. The total number of 1453 was far enough to conduct a bibliometric analysis. Glänzel and Moed (2013) recommend a sample size of at least 50 for approximation features like the “normality” distribution of means and relative frequencies. They also stated that a sample size of around 100 yielded satisfactory results.

Table 3: Data Combination and Duplicates Exclusion

Data Preprocessing Output	Information	Number	Percentage (%)
Initial results	Raw data from Scopus and WoS	2002	
	Automatic type-filter publication to remove non-related document	134	6.69
	Total publications after selecting document types (Research articles,	1868	

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	conference papers, book chapters, review papers, and proceedings)		
	Publications in WoS	670	35.90
	Publication in Scopus	1198	64.10
Duplicated removal results	Duplicated publications in both databases	415	22.20
	Duplicated publications from WoS	2	0.30
	Duplicated papers from Scopus	413	34.50
Results	Total publications after eliminating duplicates	1453	
	Publications in WoS	668	46.00
	Publications in Scopus	785	54.00

3. Results

This section presents the bibliometric analysis results of mobile learning in science education. It examined the most common topics discussed in the publications, the most productive authors and institutions, the most productive source titles and cited articles, and the most significant growth trends in research. This bibliometric analysis provides an overview of the status of mobile learning in science education and explains the research efforts to explore its potential.

3.1 The Most Common Topics Discussed on Mobile Learning in Science Education

In bibliometrics, a common topic can be related to the keyword assigned in previous publications. The keyword is a word or phrase that describes the content of a publication. It is used to help indexers and researchers find relevant publications and compare research on a particular topic. Authors, editors, and indexers typically assign keywords. However, the current study merely analyses the keywords that the respected authors dispensed in their papers. This procedure is adopted to identify trends in research concerning mobile learning in science education. Figure 1 illustrates the 20 most used keywords by previous authors.

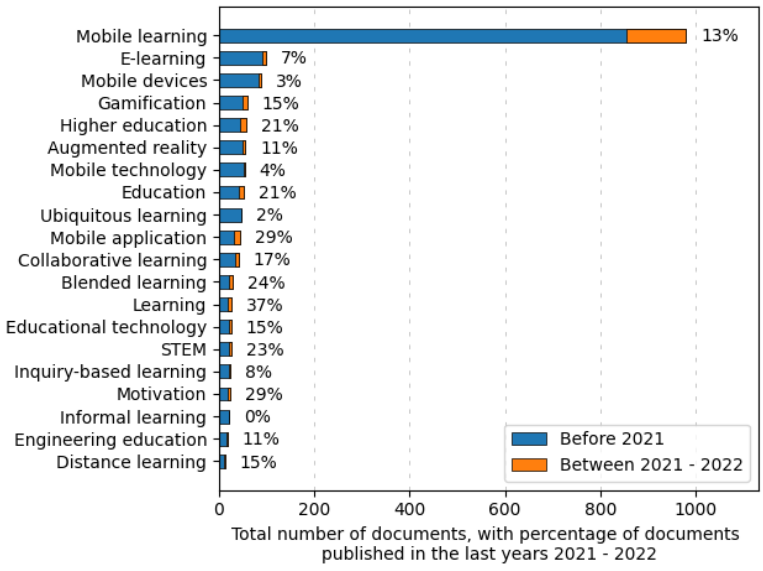


Figure 1: The top 20 Most Used Authors' Keywords

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The most used keywords in publications on mobile learning in science education are mobile learning, e-learning, mobile devices, gamification, higher education, augmented reality, mobile technology, education, ubiquitous learning, mobile application, collaborative learning, blended learning, learning, educational technology, STEM, inquiry-based learning, motivation, informal learning, engineering education, and distance learning. Based on those keywords, we can divide them into a few clusters as follows; the topic discussed in how mobile learning can foster learning in science education can be related to STEM (Science, Technology, Engineering, and Mathematics) subjects. Topics such as gamification, augmented reality, and mobile technology are discussed in terms of how they can be used to create engaging and interactive learning experiences for students. Motivation, inquiry-based learning, and informal learning are discussed regarding how they can encourage student engagement and interest in science.

3.2 The Most Productive Authors and Institutions

Productive authors are researchers who produce a large volume of work. They are usually highly organised, disciplined, and motivated individuals who thrive on meeting deadlines and achieving their writing goals. These authors may work on multiple projects at once or focus on one project until it is completed. They typically have intense research, organisation, and time management skills and may be able to write in various genres. Table 4 illustrates the ten most productive authors in publishing papers concerning mobile learning in science education, with the minimum document number being seven. The affiliated institution and country are written based on respected authors' most recent published documents.

This study highlighted that Hwang G.J. affiliated with the National Taiwan University of Science and Technology in Taiwan is a highly productive author, having published 45 documents. Looi C.K. is another productive author, having published 26 documents. Srisawasdi N. has published 14 documents. Kearney, M., published ten documents. Chu, H.C. and Tsai, C.C. are productive authors, having published eight documents. Crompton, H., Seow, P., Wang, J., and Wang, C.X. have all published seven documents.

A productive institution in publishing academic work seeks out and publishes high-quality research and scholarship. This might include inviting authors to submit work, actively promoting published work, providing feedback and support to authors, and ensuring that the institution's published works uphold the highest standards of academic rigour. It may also involve activities such as peer review and supporting authors to help them develop their ideas and make them more publishable.

Table 4: The Top 10 Most Productive Authors

Position	Author	Total	Affiliation	Country
1	Hwang, G.J.	45	National Taiwan University of Science and Technology	Taiwan
2	Looi, C.K.	26	Nanyang Technological University	Singapore
3	Srisawasdi, N.	14	Khon Kaen University	Thailand
4	Kearney, M.	10	The University of Technology Sydney	Australia
5	Chen, C.H.	8	National Taichung University of Education	Taiwan
6	Tsai, C.C.	8	National Taiwan Normal University	Taiwan

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7	Crompton, H.	7	Old Dominion University	United States
8	Seow, P.	7	Nanyang Technological University	Singapore
9	Wang, J.	7	Shandong University	China
10	Wang, C.X.	7	Beijing Normal University	China

Figure 2 shows the top 20 most productive institutions from 1990 to 2022. The National Taiwan University of Science and Technology is the most productive institution, with 32 publications. National Taiwan Normal University is the second most productive institution, with 18 publications. Nanyang Technological University, Singapore, is the third most productive institution, with 17 publications. The National University of Tainan, Taiwan, is the fourth most productive institution with ten publications.

The remaining 16 institutions in the top 20 most productive institutions from 1990 to 2022 are Penn State University (United States, nine publications), Beijing Normal University (China, eight publications), National Cheng Kung University (Taiwan, eight publications), the University of Technology Sydney (Australia, eight publications), the Education University of Hong Kong (China, seven publications), Old Dominion University (United States, seven publications), University of Hong Kong (China, seven publications), University of Hradec Kralove (the Czech Republic, seven publications), University of Hull (United Kingdom, seven publications), University of Malaya (Malaysia, seven publications), University of Michigan (United States, seven publications), Open University (United Kingdom, six publications), Peking University (China, six publications), Khon Kaen University (Thailand, five publications), University of Aveiro (Portugal, five publications), and University of Granada (Spain, five publications).

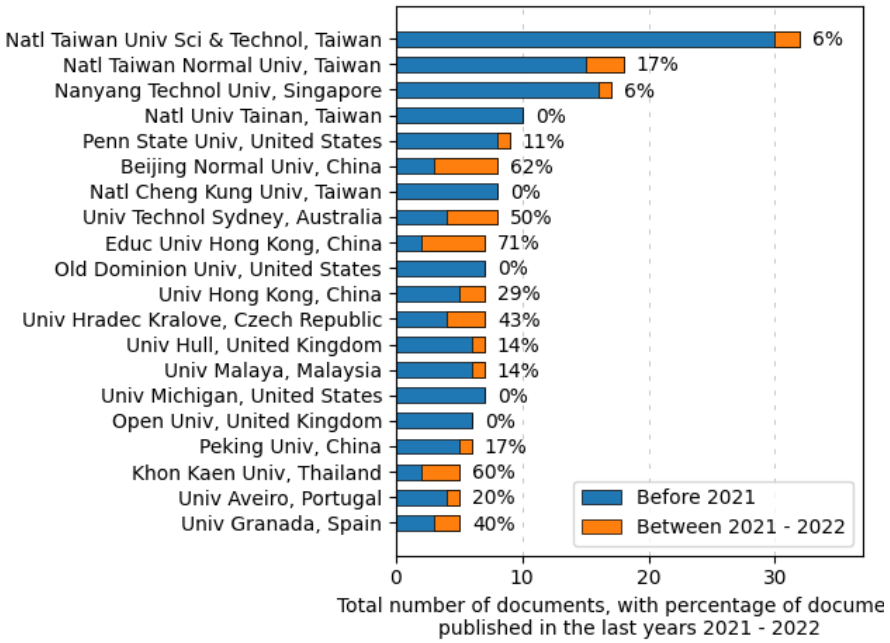


Figure 2: The Top 20 Most Productive Institutions

3.3 The Most Productive Source Titles and Cited Articles

Table 5 includes the leading 20 mobile learning in science education source titles based on the number of publications. This resource is essential for readers and researchers because it provides an overview of the most influential source volumes on this topic. In addition, readers

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and researchers can utilise the offered data to analyse the growth rate, average number of documents per year, and percentage of documents published in the journal's most recent years. This information assists in evaluating the relevancy of the source's titles and the quality of its articles. In addition, readers and researchers can utilise this information to find the most helpful source titles for mobile learning in science education. This information can be utilised to decide which source titles are most relevant to the topic of the investigation. By providing this resource, readers and researchers may easily select the most productive source titles and evaluate their relevance and quality based on the provided data.

With 39 documents released, Computers & Education is one of the most prolific source titles for mobile learning in science education. The journal's AGR (Average Growth Rate) is -3, and its ADY (Average documents per year) is 2, indicating that its publications are referenced three times more frequently than the average journal in its discipline. The journal's PDLY (Percentage of documents in the previous two years) is 10.3, which indicates that 10.3% of its papers have been published in the last two years. The journal's h-Index of 30 indicates that 30 articles have been referenced at least 30 times, making it one of the most influential publications in its field. This journal is an international publication devoted to the investigation, design, development, application, and assessment of computer-based instructional technology, learning technology, and associated educational applications.

Lecture Notes in Computer Science is an additional convenient source. This source is ranked second and has produced 35 documents on mobile learning in science education. This source is a series of computer science monographs published by Springer Science+Business Media as a book series. The theoretical and practical components of computer science, artificial intelligence, and bioinformatics are covered in Lecture Notes in Computer Science. With 30 documents connected to mobile learning in science education, the International Journal of Mobile Learning and Organisation is placed third as the most productive source title. This publication examines the technological and organisational aspects of mobile learning and its potential, problems, and limitations. It publishes research on the design and development of mobile learning, mobile learning applications, and their impact on students and institutions.

Table 5: The Top 20 Most Productive Source Titles

No.	Source Title	Publication	AGR	ADY	PDLY	h-Index
1	Computers & Education	39	-3	2	10.3	30
2	Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)	35	-3	1	5.7	6
3	International Journal of Mobile Learning and Organisation	30	-1.5	2	13.3	11
4	ACM International Conference Proceeding Series	24	0	1	8.3	5
5	International Journal of Interactive Mobile Technologies	22	-2	2	18.2	9
6	Educational Technology & Society	21	0.5	1	9.5	17
7	Communications in Computer and Information Science	18	0	1	11.1	4
8	Interactive Learning Environments	18	-1.5	1.5	16.7	10
9	Lecture Notes in Electrical Engineering	16	0	0	0	2
10	CEUR Workshop Proceedings	15	-1	0	0	4

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11	Journal of Computer Assisted Learning	14	1.5	2	28.6	11
12	British Journal of Educational Technology	13	0	2.5	38.5	10
13	Advances in Intelligent Systems and Computing	11	-1.5	1.5	27.3	1
14	Education and Information Technologies	11	1.5	2.5	45.5	6
15	Computer Applications in Engineering Education	10	1	3	60	6
16	Journal of Science Education and Technology	10	-0.5	1.5	30	7
17	Computers In Human Behavior	9	0	0	0	9
18	Journal of Physics: Conference Series	9	-0.5	0.5	11.1	3
19	Education Sciences	8	1	3.5	87.5	4
20	TechTrends	8	-0.5	0	0	5

Note. AGR = Average growth rate; ADY = Average documents per year; PDLY = Percentage of documents in last years.

Most cited articles have been published in well-respected, peer-reviewed journals and referenced by other authors in their research. These articles tend to have a high impact factor, meaning they are widely read and influential in the field. Table 6 depicts 11 articles with more than 200 citations, indicating that those 11 papers generated much interest and attention in their respective fields.

Table 6: Most-cited Articles with 200 Citations

No.	Source Reference	Title	Source Title	Citation	Document Type
1	Wu et al. (2013)	Current status, opportunities and challenges of augmented reality in education	Computers & Education	907	Article
2	Sung et al. (2016)	The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis	Computers & Education	594	Article
3	Rahimi et al. (2014)	Mobile cloud computing: A survey, state of art and future directions	Mobile Networks and Applications	305	Conference Paper
4	Chu et al. (2010)	A two-tier test approach to developing location-aware mobile learning systems for natural science courses	Computers & Education	286	Article
5	Chiang et al. (2014)	An Augmented Reality-based Mobile Learning System to Improve Students' Learning Achievements and Motivations in Natural Science Inquiry Activities	Educational Technology & Society	283	Article
6	Su & Cheng (2015)	A mobile gamification learning system for improving the learning motivation and achievements	Journal Of Computer Assisted Learning	264	Article
7	Kamarainen et al. (2013)	EcoMOBILE: Integrating augmented reality and	Computers & Education	263	Article

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		probeware with environmental education field trips			
8	Tan et al. (2014)	Predicting the drivers of behavioral intention to use mobile learning: A hybrid SEM-Neural Networks approach	Computers In Human Behavior	237	Article
9	Al-Emran et al. (2018)	Technology Acceptance Model in M-learning context: A systematic review	Computers & Education	213	Review
10	Hwang & Wu (2014)	Applications, impacts and trends of mobile technology-enhanced learning: A review of 2008-2012 publications in selected SSCI journals	International Journal of Mobile Learning and Organisation	201	Article
11	Zydney & Warner (2016)	Mobile apps for science learning: Review of research	Computers & Education	201	Review

Based on Table 6, Wu et al. (2013) wrote the top-cited paper, "Current Status, opportunities and Challenges of augmented reality in Education", published by Computers & Education. This paper obtained 907 citations until January 2023. This article overviews definitions, taxonomies, and artificial intelligence technologies. This paper is highly cited due to its comprehensive overview of augmented reality in education. Also, it provides an up-to-date look at the current technologies and opportunities and a comprehensive overview of the field's challenges. Additionally, the paper offers a detailed taxonomy of the various types of augmented reality technologies, which provides a valuable framework for further research. The paper is an essential resource for understanding the field's current state and further exploring the potential for augmented reality in education.

With 594 citations, the article "The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis" has become the second-most-cited article. This article was written by Sung et al. (2016) and published by Computers & Education. The article indicates that mobile device use in education has a moderate effect size on average. The article was often cited due to its thorough evaluation of the impact of mobile device integration on student academic attainment.

Rahimi et al. (2014) wrote the third-ranked most-cited article titled "Mobile Cloud Computing: A Survey, state of the Art and future directions". Mobile Networks and Applications published this conference paper. Until January 2023, this article obtained 305 citations. The results of this article demonstrate the importance of Mobile Cloud Computing (MCC) in various technological fields. The high number of citations shows that the paper has been widely read and accepted by the research community, confirming the significance of MCC in the modern world. This suggests that MCC is a critical study and research topic and that universities recognise its importance.

3.4 The Publication Growth Trends on Mobile Learning in Science Education

Figure 3 compares the publication growth on mobile learning in science education in the WoS and Scopus databases. The publication growth in both databases started in 2002 and 2004, respectively. In the beginning, the growth rate in both databases was relatively low. However, from 2005 to 2013, the publication growth in Scopus increased rapidly, with seven publications in 2005, nine publications in 2006, 18 publications in 2007, 26 publications in 2008, 40 publications in 2009, 43 publications in 2010, 61 publications in 2011, 67 publications in 2012,

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and 66 publications in 2013. Similarly, the publication growth in WoS also increased rapidly from 2003 to 2013, with two publications in 2003 and 2004, three publications in 2005 and 2006, eight publications in 2007, 11 publications in 2008 and 2009, 26 publications in 2010, 18 publications in 2011, 21 publications in 2012, 30 publications in 2013, and the publication is WoS has increased significantly until 2018 with 67 publications.

After 2013, the publication growth in Scopus declined. In Scopus, the publication growth declined in 2014, with 58 publications, in 2015 (48 publications), 2016 (47 publications), 2017 (44 publications), and 2018 (44 publications). However, the publication growth started to rise in 2019, with 61 publications dropping to 58 in 2020 and 40 in 2021. Nevertheless, it started to increase in 2020 with 45 publications. Comparatively, the publication growth trends of WoS grew dramatically between 2014 and 2018 compared to Scopus. In WoS, the growth of publications increased with 43 publications in 2014, 57 in 2015, 67 in 2016, and 68 in 2017. Nevertheless, in 2018 the number of publications started to reduce, with 67 publications in 2018, 54 publications in 2019, 69 publications in 2020, 65 publications in 2021, and 42 publications in 2020.

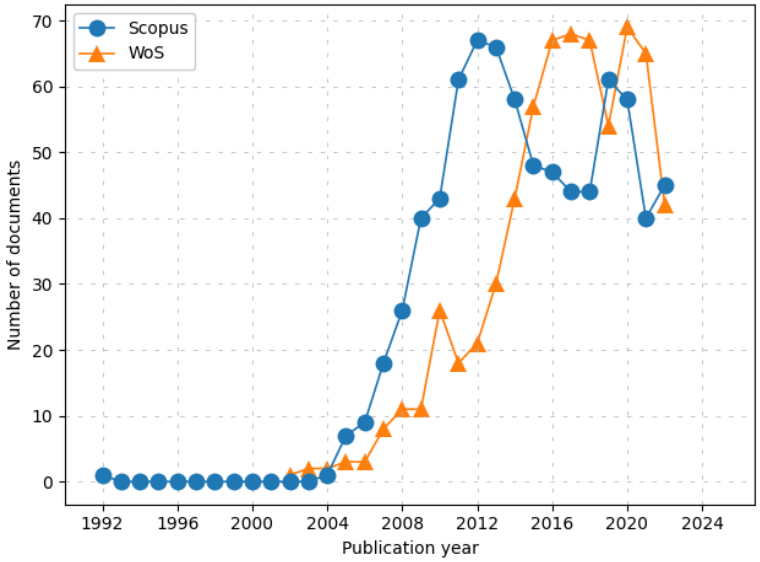


Figure 3: Publication Trends

4. Discussion

Mobile learning, or mobile devices to support learning and instruction, is gaining popularity in science education. It is possible to analyse the influence of this innovative teaching and learning method on science education through bibliometric analysis. This study assessed the evolution of mobile learning-related scientific papers that were indexed in the Scopus and WOS databases. ScientoPy was utilised to monitor publication patterns by visualising and tabulating data gathered during the evaluation process. This study summarises the research on mobile learning in science education to enable readers and researchers to get vital ideas for future research.

A bibliometric study of the literature on mobile learning in science education might provide insight into the discipline's current state and future directions. For instance, it might highlight which topics have received the most attention and require additional study. The results of the most-discussed topic highlight the significance of mobile learning in science education. It

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emphasises the significance of mobile learning, e-learning, mobile devices, gamification, and augmented reality within the area. This demonstrates the emphasis on incorporating technology into education and employing gaming features to interest students (Baek et al., 2020; Licorish et al., 2018). To maximise its potential benefits, science educators must comprehend the efficacy and impact of mobile learning and its associated problems and repercussions.

Higher education, mobile technology, ubiquitous learning, mobile application, collaborative learning, blended learning, learning, educational technology, STEM, inquiry-based learning, motivation, informal learning, engineering education, and distance learning highlight the breadth of the area. By knowing these themes, science educators may better plan for the effective integration of mobile learning in their classrooms and give students the most remarkable learning experiences possible. Consistent with other research, the findings of this study indicate that mobile learning is a valuable tool for science education (Coelho et al., 2023; Golenhofen et al., 2020; Liu et al., 2014). Mobile learning can improve science education by enabling students to access course materials, engage in interactive activities, and receive individualised feedback (Bai, 2019; Salhab and Daher, 2023). Additionally, mobile learning can enhance student engagement and motivation (Alioon and Delialioğlu, 2019; Jeno et al., 2019). Therefore, this study supports the view that mobile learning is vital for science education.

In addition, this bibliometric study can provide information on the most prolific authors and institutions in the mobile learning and science education literature. Productive authors play a crucial role in bibliometric analysis, frequently driving research and innovation in a specific sector. By identifying the most prolific writers, bibliometric analysis can provide significant insights into the trends and changes in a study field and assist in identifying the main actors and influencers. According to the analysis, the most productive author, Hwang G.J., affiliated with the National Taiwan University of Science and Technology in Taiwan, published 45 documents on mobile learning in science education. Looi C.K. is another productive author, having published 26 documents. Srisawasdi N. has published 14 documents. The most productive institution discovered in this study is the National Taiwan University of Science and Technology, with 32 publications. The results of the most productive authors and institutions provide a valuable resource for researchers and institutions looking to develop their mobile learning initiatives. Also, it can provide an invaluable roadmap for other researchers and institutions interested in exploring mobile learning in science education by highlighting the most productive authors and institutions.

This study showed that Computers & Education, Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Bioinformatics), and the International Journal of Mobile Learning and Organisation were the top three most productive titles published in mobile learning in science education. Knowing the most productive source titles in mobile learning in science education is crucial because it provides insights into the primary outlets for research in the field and the venues where the most significant contributions are being made.

These outcomes indicate that Computers & Education is the most popular source for computer science research. This could be due to the journal's broad scope and the extensive spectrum of relevant topics, such as artificial intelligence, bioinformatics, and mobile learning. The journal has an international readership and contributions from many different nations. This makes it an appropriate venue for distributing research results to a large audience. The second most productive publication is Lecture Notes in Computer Science. This could be related to its

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emphasis on the most recent advancements in computer science, which makes it an excellent forum for discussing cutting-edge research. In addition, many of the journal's publications are cited by other scholars, demonstrating the publication's prestige in the field. International Journal of Mobile Learning and Organization is the source which ranked in the third position. This may be owing to the journal's minimal scope and emphasis on a single field of computer science. In addition, the journal is relatively young and may not have had as much time as the other two sources to develop its readership and contribution base.

Bibliometric analysis of the literature on mobile learning in science education can also provide information about the impact of mobile learning on the field. The results of this study indicate that the top three cited articles are "Current Status, Opportunities and Challenges of Augmented Reality in Education" (Wu et al., 2013), "The Effects of Integrating Mobile Devices with Teaching and Learning on Students' Learning Performance: A Meta-Analysis and Research Synthesis" (Sung et al., 2016), and "Mobile Cloud Computing: A Survey, State of Art and Future Directions" (Rahimi et al., 2014). These three articles have been seen as ground-breaking and keystones in mobile computing, augmented reality and cloud computing and have been widely cited in the literature.

Wu et al. (2013) explored augmented reality's status, opportunities, and educational challenges. The article discussed how augmented reality could help to enhance the educational experience and improve the outcomes of students. The authors discussed the advantages and drawbacks of the technology and made recommendations for its potential application in the classroom. Sung et al. (2016) investigated how integrating mobile devices with teaching and learning influences students' learning performance. The authors conducted a meta-analysis of existing literature to examine the effects of mobile devices on student achievement, engagement, and motivation. The study suggested that incorporating mobile devices into the classroom can help improve student performance. Rahimi et al. (2014) surveyed mobile cloud computing, examining the current state of the technology and discussing potential future directions. The authors discussed the potential applications of mobile cloud computing and identified some areas for further research. By looking at the number of citations for articles related to mobile learning, researchers can gain insight into the relative importance of mobile learning to science education. This can help researchers better to understand the influence of mobile learning on the field and to identify potential research opportunities.

The most significant trend in research on mobile learning in science education is the increasing number of publications in the field. The increasing number of publications in WoS and Scopus evidences this trend. In WoS, publications increased from two in 2003 to 69 in 2021. Meanwhile, in Scopus, the number of publications increased from one in 2004 to 66 in 2013. This trend indicates that mobile learning in science education has become a widespread and growing field of research. In addition, the trend in Scopus from 2014 to 2018 indicated a decline in publications. This could be because research on mobile learning in science education had already been established, and the number of publications was beginning to plateau. However, since 2019, the trend has risen again, indicating renewed interest in the field.

The publication growth trends in Scopus and WoS databases have been similar but with some differences. Both databases started with one publication in 2002 and 2004, respectively. Both databases have seen rapid publication growth from 2005 onwards, with the growth in Scopus being slightly faster. From 2005 to 2013, the publication growth in Scopus increased rapidly from seven publications to 66 publications. However, the growth in Scopus declined in 2014 with 58 publications and continued to decline until 2018 with 44 publications. The publication

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growth in Scopus started to rise in 2019 with 61 publications and dropped to 58 publications in 2020 and 40 publications in 2021, but it started to increase again in 2020 with 45 publications. Contrariwise, publication growth in WoS increased steadily from 2003 to 2021, with two publications in 2003 and 2021 and three in 2005 and 2006. From 2007 to 2021, publications increased steadily from 8 to 69. In 2020, the number of publications dropped to 42. The publication growth in WoS has been slower than in Scopus but has been more stable.

The rapid growth in publications on mobile learning in science education seen in both WoS and Scopus is likely due to the growing importance of mobile learning in science education. The rise of mobile devices has made it easier for students to access and consume educational materials, allowing them to learn more conveniently and flexibly than ever before (Diao and Hedberg, 2020; Jeong, 2022; Sattarov and Khaitova, 2019). Moreover, the rapid growth in mobile learning publications may also be due to the increased availability of research and resources related to mobile learning and an increased interest in the potential of mobile learning for enhancing the quality of science education. In comparison, Scopus's recent publication growth decline may be due to a decrease in interest in mobile learning in science education and a lack of new research in the field.

4.1 Limitation of the Current Study

Bibliometric analysis is a valuable tool for understanding the research landscape on mobile learning in science education. It can provide insights into the trends and patterns of research in the field, including the research types, the institutions conducting the research, the authors and keywords associated with the research, and the most cited publications. Nevertheless, it is vital to be aware of the limitations of bibliometric analysis when using it to understand the research landscape.

First, bibliometric analysis is limited by the data included in the analysis. Bibliometric analysis using Scopus or Web of Science data is necessarily limited to the articles included in those databases. As its coverage of the literature is incomplete, any bibliometric analysis approximates the research landscape and must be interpreted cautiously. In addition, bibliographic databases may not include all relevant literature, mainly grey literature.

Second, impacts scores such as the h-index are often used to measure a researcher's or program's success but are limited by the publications used in the analysis. For example, if a researcher publishes in a journal that is not indexed in Scopus or WoS, the h-index will not accurately reflect the total contribution of that article.
Third, bibliometric analysis is limited by the data analysis methods. For example, simple descriptive statistics may not accurately depict the research landscape. More sophisticated methods, such as network analysis, are essential for a more comprehensive understanding of the research landscape.

4.2 Recommendations

Future research proposals for bibliometric analysis of mobile learning in science education would entail expanding the field's study coverage. This can be accomplished by amassing additional data from many sources, such as online databases, journals, books, and conference proceedings. There is also a need for research into the impact of mobile learning on science education results. There could be a comparison of how well students do on learning activities while using mobile devices versus when using more conventional methods of instruction.

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Additional studies could target the most productive mobile learning activities for scientific instruction. For this purpose, it may be helpful to examine features of the mobile learning environment, including their level of interaction, ability to adapt to different settings, and accessibility. Mobile learning, such as apps, Virtual reality or Augmented reality (VR/AR), remote labs, and educational technology (EdTech) for teamwork and collaboration, is possibly the future of science education; therefore, researchers may investigate the best practices for implementing it in schools.

Another suggestion that would add value to the study would be to look at how different factors affect the spread of mobile learning in the science classroom. This may entail surveying students' and educators' experiences with mobile education and their thoughts on its efficacy. Further study should examine how using mobile devices for learning affects science instruction in different contexts. One approach would be to investigate the use of mobile learning across various nationalities, regions, and economic backgrounds.

To conclude, assessing the field's current state and identifying areas for future study is made much easier through the bibliometric analysis of mobile learning in science education. More in-depth research into the usage of mobile learning in science education is needed so that researchers can better understand how it is utilised and how it may be enhanced to serve students' needs better.

5. Conclusion

The bibliometric analysis of mobile learning in science education has yielded essential new understandings about the state of the discipline. This research demonstrates the rising interest in and potentially transformative impact of mobile learning in the delivery of science education. In addition, the analysis has shown that there is a growing body of work in this field and that the nature and scope of that work are becoming more and more multifaceted. Mobile learning in science education has been the topic of many studies, particularly its development, implementation, and evaluation.

Possible future research and development avenues can be gleaned from the bibliometric analysis's findings. For instance, the findings indicate that more study is required in mobile learning to educate students on complicated topics and to create efficient evaluation methods. Further study is required to ascertain the influence of mobile learning on student outcomes and to determine the most efficient means by which it can be incorporated into current educational frameworks.

The bibliometric analysis of mobile learning in science education has provided valuable insights into the field's current state. It has demonstrated that mobile learning has the potential to revolutionise how science education is delivered and that research in this area is becoming increasingly interdisciplinary and complex. The analysis results can inform future research and development in this area and ensure that mobile learning is used to its fullest potential in science education. Inevitably, this bibliometric review of mobile learning in education only scratches the surface of a vast body of literature. As a result, some parts of the theme have been disregarded.

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