MODESTUM

EURASIA Journal of Mathematics, Science and Technology Education, 2023, 19(5), em2268
ISSN:1305-8223 (online)

OPEN ACCESS

Review Article

https://doi.org/10.29333/ejmste/13162

Mobile learning in mathematics education: A systematic literature review of empirical research

Dung Minh Tang [1], Cam Thi Ngoc Nguyen [1*], Huy Ngoc Bui [1], Hung Thai Nguyen [1], Khai Tuan Le [1], Khanh Le Gia Truong [1], Nha Thanh Tran [1], Nguyen Khoi Vo [1], Tien Thuy Nguyen [1]

[1] Ho Chi Minh City University of Education, Ho Chi Minh, VIETNAM

Received 12 July 2022 ▪ Accepted 25 March 2023

Abstract

Mobile devices (e.g., smartphones and tablets) are spreading globally, along with decreasing prices and increasing support utilities with the characteristics of availability, flexibility, portability, individuality, connectivity, and social interactivity. The rise of mobile devices/ technologies in school inspired educational researchers to introduce the term "mobile learning" to push the boundaries of traditional pedagogy. This study was a systematic review of 52 articles related to mobile learning in mathematics education in 2008-2021. It answered the questions about distribution, major research purposes, approaches, methods. The articles for review were chosen using a three-stage methodology: read, select criteria, and summarize. This review study of mobile learning presents findings, which highlighted gaps in existing literature on the topic and has provided insights, can become a platform and guidance for researchers, educators, and policy makers for future research.

Keywords: mobile device, mobile technology, mobile learning, mathematics education

INTRODUCTION

From Mobile Device to Mobile Learning

Mobile devices (e.g., smartphones and tablets) are spreading globally while decreasing prices and increasing support utilities. 95% of the world's population has access to a mobile broadband network (International Telecommunication Union [ITU], 2021). In the trend of increasing, mobile subscriptions with broadband capability are reaching 83 subscriptions per 100 people in 2021. The recent proliferation of mobile technologies profoundly affect how human access and interact with information or data and communicate (Liu et al., 2014). Significantly, the fifth generation of mobile technologies (5G) allows connecting many people, things, and data with minimal delay, thus opening a perspective, where real life and the virtual or digital worlds overlap. Moreover, the availability, flexibility, portability, individuality, connectivity, and social interactivity of mobile devices seemed very suitable for young people and quickly adopted by generation Z as a cultural tool worldwide.

Mobile devices and technologies influenced school activities during the last decade differently from conventional devices (e.g., personal computers) (Liu et al., 2014). Indeed, their feature of 'anytime' and 'anyplace' has broken traditional classrooms' constraints and given rise to outdoor, informal learning activities (Criollo-C et al., 2021; Qureshi et al., 2020; Sung et al., 2016). Thus, their affordances in educational scenarios have aroused the interest of educators and researchers with expectations of learning innovation (Lai, 2019).

The rise of mobile devices and technologies in school inspired educational researchers to introduce the term "mobile learning" (or "m-learning") to push the boundaries of traditional pedagogies. Mobile learning involves the use of mobile technology, either alone or in combination with other information and communication technology to enable learning at any time and in any

✉ dungtm@hcmue.edu.vn ✉ camntn@hcmue.edu.vn **(*Correspondence)** ✉ buingochuy02tdn@gmail.com
✉ likeasandwich529@gmail.com ✉ iamkhaifromvn@gmail.com ✉ tlgk0110@gmail.com ✉ nhatran189999@gmail.com
✉ Vokhoinguyen2003@gmail.com ✉ thuytien1904lk@gmail.com

Contribution to the literature

- A systematic review of the literature is used in this study.
- Mobile learning in mathematics education settings is analyzed for its year, ranked, geographical, and educational level distribution; purposes, methods, and it provides a current synthesis for the scholarly community.
- For advancement of mobile learning in mathematics education, this review provides new information.

place (Grant, 2019). Learning can unfold in various ways: people can use mobile devices to access educational resources, connect with others, or create content, both inside and outside classrooms. Mobile learning also encompasses efforts to support broad educational goals, such as the effective administration of school systems and improved communication between schools and families (UNESCO, 2013). It aligned with the emphasis on two crucial features of mobile learning, "action" and "contextualization", mentioned by recent educational researchers (Chung et al., 2019).

Many advantages of mobile learning have been described, including expanding the reach and equity of education, facilitating personalized learning, providing immediate feedback and assessment, enabling anytime, anywhere learning, ensuring the productive use of time spent in the classroom, building new communities of learners, supporting situated learning, enhancing seamless learning, bridging formal and informal learning, minimizing education disruption in conflict and disaster areas, assisting learners with disabilities, improving communication and administration, and maximizing cost-effective (UNESCO, 2013). Mobile learning impacted positively students, educational institutions, and teachers in constructivist learning, student behavior, learning spaces, collaborative learning, informal and self-directed learning, resources for teachers, technology and support, affordability and portability, availability and flexibility, and motivational education (Criollo-C et al., 2021). Although there are some barriers and challenges, for example, financial limitations, teachers' skills for effective implementation, and health and psychological issues (Bano et al., 2018), mobile learning is developed fairly quickly and is evaluated as a learning platform (thought technology) that has many prospects for the future (Drigas & Pappas, 2015; Qureshi et al., 2020).

According to Crompton and Burke (2020), the trend of using mobile technologies, especially applications on mobile, is increasingly popular in mathematics education. Many recent innovations in mobile technology promote the convergence and the overlap of different spaces: space of mathematics knowledge, physical space of real life and space of technologies (Abidin et al., 2017), such as augmented reality on mobile devices. Mobile learning provides personalized and collaborative opportunities for students through specific and immediate feedback on practicing mathematics skills and applying mathematics knowledge to the real context everywhere and every time (Al-Khateeb, 2018; Borba et al., 2016; Fabian & Topping, 2019; Fabian et al., 2018; Larkin & Calder, 2016). Many new mathematical tasks can appear in this mobile learning context. They offer new possibilities for accessing mathematics knowledge and skills in a manner more exciting and suitable for children born in the tech boom (Acikgul & Sad, 2020). Thus, teaching mathematics in the 21st century can overcome the constraints of traditional teaching in the previous centuries, for example, learning space, time, interaction, and connection (Meletiou-Mavrotheris et al., 2019).

Literature Reviews on Mobile Learning

Despite being a new research field, with the first research publications in the late 1990s (Wingkvist & Ericsson, 2011), mobile learning has attracted the interest of more and more researchers and educators with various approaches and methods. In the context of the proliferation of studies, reviews are the necessary studies, providing the current state-of-the-art to evaluate the impact, understand the potential of mobile learning in education, and thereby help to orient new studies, mandate appropriate education policies, and appropriately apply them to teaching and learning (Bano et al., 2018; Crompton & Burke, 2018) (**Table 1**).

Each literature review has valuable contributions but will be limited to the data (search strategy, inclusion and exclusion criteria, and period of publication), research object, and interest (research question). In **Table 1**, most of the systematic reviews are not subject-specific. There are only two for a particular subject: science (Crompton et al., 2016) and mathematics (Crompton & Burke, 2017). Nevertheless, Crompton and Burke's (2017) review provides only valuable information about mobile learning in mathematics education five years ago. Meanwhile, mathematics is one of the three subjects that attract the most research on mobile learning (Crompton et al., 2017; Liu et al., 2014; Sung et al., 2019).

On the other hand, over the past five years, technology has made great strides and spread widely in mathematics education, especially with the significant effect of the COVID-19 pandemic. This context undoubtedly has an impact on mobile learning in mathematics education. Thus, we need to update this theme's big picture of studies.

Table 1. Some highly cited literature reviews on mobile learning

Author(s)	n	Period	Research object	Interest of review
Sung et al. (2019)	342	2006-2016	Experimental designs in mobile learning research	Experimental designs; mechanisms to ensure baseline equivalence between experimental & control groups; appropriateness of parametric statistical methods; sample sizes; measurement tools (reliability & validity); levels of rigor; information about effect sizes; & statistical powers
Krull and Duart (2017)	233	2011-2015	Mobile learning in higher education	Research methods; research trends (purposes, themes, & technologies); & relating to previous reviews from 2001 to 2010
Crompton and Burke (2020)	186	2014-2019	Mobile learning in preK-12 classroom	According to SAMR framework, level of technology integration & trend in specific grade levels & subject areas
Wu et al. (2012)	164	2003-2010	Mobile learning	Major research purposes, methodologies, outcomes; types of mobile devices; different categories of disciplines & courses; & highly-cited articles
Hwang and Tsai (2011)	154	2001-2010	Mobile & ubiquitous learning	Status of articles, sample groups, & learning domains
Crompton et al. (2017)	113	2010-2015	Mobile learning in PK-12 education	Major research purposes, methodologies, & outcomes; subject matter domains, educational levels, & educational contexts; mobile devices; geographical distribution; & learning theories
Sung et al. (2016)	110	1993-2013	Effect of mobile devices on students' learning performance	Use of mobile devices; effectiveness on student learning achievement; moderator variables; & advantages & disadvantages
Lai (2019)	100	Before February 2019	Trends of mobile learning	Research design & purposes; learning devices, activities, course, & learning space; subjects, sample size, analysis method, & measurement issues; & top-10 most productive authors
Al-Emran et al. (2018)	87	Before May 2018	Technology acceptance model in mobile learning	Main research purposes; main research methods; active countries; main disciplines/contexts; main educational levels; & distribution
Crompton and Burke (2018)	72	2010-2016	Mobile learning in higher education	Major research purposes, methodologies, & outcomes; subject matter domains, educational levels, & educational contexts; mobile devices; & geographical distribution
Chung et al. (2019)	63	2010-2016	Experimental mobile learning research	Evaluating & categorizing studies
Liu et al. (2014)	63	2007-September 2012	Mobile learning in K-12 education	Issues; enhancement of teaching/learning; trends (e.g., growth of research, distributions in subject matter, regions, & school levels); difference between K-12; & adult education
Crompton et al. (2016)	49	2000-2016	Mobile learning in science	Major research purposes, methodologies, & outcomes; science concepts, educational levels, & educational contexts; mobile devices; geographical distribution
Crompton and Burke (2017)	36	2000-2017	Mobile learning in mathematics	Major research purposes, methodologies, & outcomes; mathematical concepts, educational levels, & educational contexts; mobile devices; & geographical distribution
Pimmer et al. (2016)	36	2000-2013	Mobile & ubiquitous learning in higher education	Categories of learning design & outcomes
Kumar and Mohite (2017)	23	Before 2017	Usability of mobile learning applications	Number of research activity; attributes of evaluation; research methodologies of evaluation; & limitations

Note. n: Number of articles

This study is interested in reviewing studies on mobile learning in mathematics education as an extension of Crompton and Burke (2017) due to the growth of interest among educational researchers and practitioners (Borba et al., 2016; Fabian et al., 2018).

Table 2. Inclusion & exclusion criteria

Inclusion criteria	Exclusion criteria
Mobile learning in mathematics education	Not specific for mathematics education
Empirical research	Review research
Original research	Thesis
Written in English language	Chapter/section of book
Published between 2008 & 2021	Mobile device must not be laptops
Belong to a scientific journal indexing in Scimago journal ranking (Q1-4)	Mobile device must not be netbooks
	Mobile device must not be calculators

Table 3. Journals & number of articles for analysis (n)

Journal	n
Australasian Journal of Educational Technology	1
Australian Educational Computing	1
British Journal of Educational Technology	1
Communications in Computer & Information Science	1
Computer-Aided Design & Applications	1
Contemporary Educational Psychology	1
Distance Education	1
Educational Technology Research & Development	3
Electronic Journal of e-Learning	1
Interactive Learning Environments	1
Interdisciplinary Journal of Practice, Theory, & Applied Research	1
International Journal for Technology in Mathematics Education	1
International Journal of Applied Engineering Research	1
International Journal of Emerging Technologies in Learning	5
International Journal of Instruction	1
International Journal of Interactive Mobile Technologies	2
International Journal of Mobile & Blended Learning	5
International Journal of Science & Mathematics Education	1
Journal of Computing in Higher Education	1
Journal of Educational Computing Research	1
Journal of Information Technology Education: Innovations in Practice	1
Journal of Information Technology Education: Research	1
Journal of Interactive Learning Research	2
Journal of Research on Technology in Education	2
Learning, Media & Technology	1
Mathematics Education Research Journal	9
On the Horizon	1
South African Journal of Education	1
TechTrends	2
ZDM-International Journal on Mathematics Education	1
Total	52

Research questions

In the context of the above background, the primary focus of our study was to synthesize the articles involving mobile learning in mathematics education published from 2008[1] to 2021. The research questions were, as follows:

1. What was their distribution (e.g., by year, ranking, geography, and education level)?
2. What were their major research purposes, approaches, and methods?

METHODS

Search Strategy

The research team used keywords to search multiple data sources for answers to research questions. They were, as follows:

(1) mobile learning terms such as "mobile learning", "mobile technology", "mobile device", "cellphone", "smartphone", "tablet", "iPhone", "iPad" and

(2) mathematics education terms such as "mathematics education", "teaching mathematics", "learning mathematics", "mathematics", "maths", "geometry", "algebra", "calculus", "statistics", "probability".

The conjunction "AND" was used to join the two sets of terms. The 176 articles were retrieved from an electronic search of educational databases: Springer, ScienceDirect, Taylor & Francis, Emerald Insight, SAGE journals, ProQuest, JSTOR, and Google Scholar and aligned with inclusion and exclusion criteria (**Table 2**).

However, only 52 articles that met all inclusion and exclusion criteria were selected for review (**Table 3**) following a three-stage review procedure (**Figure 1**).

Analysis Strategy

The 52 articles were analyzed according to the following seven factors:

(1) year of publication,

(2) Scopus quartile ranking (Q1, Q2, Q3, and Q4),

(3) country, where the study was conducted,

(4) educational level of participants (e.g., kindergarten, primary, secondary school, and university),

[1] iPhone & its store of applications were introduced in 2007 & 2008. They innovated mobile devices whose features have been vastly extended by developers & opened a new way of using mobile devices users could customize according to different needs.

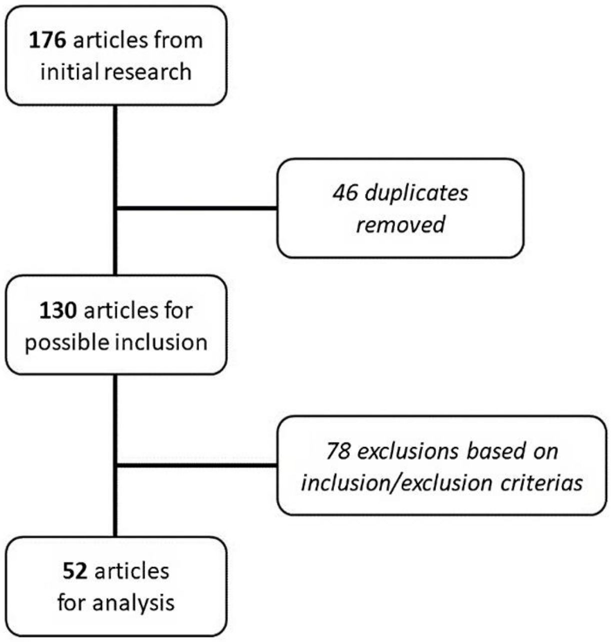


Figure 1. Diagrammatic presentation of literature search & review process (Source: Authors' own elaboration)

(5) research purpose,

(6) research approaches (e.g., qualitative, quantitative, and mixed), and

(7) research method.

The research purposes were coded following Bano et al.'s (2018) 13 studies focused empirical studies on mobile learning for science and mathematics school education (**Table 4**).

And coding of the research methods was a reuse from Wang et al. (2018), including self-report measures, performance assessments, open-ended questionnaires, interviews, and observations (**Table 5**).

Data Coding and Analysis

The study was conducted in the following manner:

1. **Step 1.** Create a form and fill it up using the data from each article that was selected for analysis.
2. **Step 2.** Synthesize data based on the seven analysis strategy-identified factors. To complete step 2, two groups had to be synthesized.

   Group 1 is responsible for synthesis from factor (1) to factor (4). Group 2 is responsible for synthesis from factor (5) to factor (7).

   The data were coded as **Table 6** by three members and double-checked by three others in each group. During the encryption process, all

Table 4. Number of articles (n) per research purpose

Study focus	Description	n
Effectiveness of using app	To investigate effectiveness & ease of using app in facilitating student learning	12
Design of app	To investigate design of apps to assist student learning	6
Technology implementation	Evaluate & investigate effects of technology enhanced curriculum on student learning	11
Evaluating student perceptions	Investigating impact of mobile learning apps on students' motivation & attitudes	9
Collaborative learning	Investigating potential of mobile technologies to support collaborative problem-solving skills of students in groups	5
Student engagement	Explores how mobile learning facilitates development of learning activities with potential to increase student engagement & confidence	10
Constructivist learning	Investigating use of mobile technologies from a constructivist learning perspective	1
Facilitators for mobile learning	Investigating teachers' & students' experiences on factors that aid learning while using educational apps	5
Barriers for mobile learning	Investigating teachers' & students' experiences on factors that hinder learning while using educational apps	8
Curriculum development	Evaluating effects of mobile technology enhanced curriculum on student learning	12
Teaching strategies in mobile learning	Investigating impact of different teaching strategies on learning with mobile devices	9
Supporting student from underdeveloped regions	Explores effectiveness of a game-based mobile learning model for children living in underdeveloped regions	2
Scaffolding App selection for teaching	Process of creating, developing, & testing a mobile science application rubric to aid secondary science classroom teachers in selecting & rating science applications	2

Table 5. Number of articles (n) per research method, instruments, & techniques

Research method	Instruments/techniques	n
Performance assessments	Pre/post-tests	25
Self-report measures	Questionnaires, scales, & surveys	18
Observations	Class recordings & notes	18
Interviews	Oral responses, discussions between researchers & teachers, & students	17
Open-ended questionnaires	Written responses from questionnaire question	14

Table 6. Coding & description factors

Group	No	Factor	Description	Code
1	1	Year	Synthesize & analysis of years of publications for period 2008-2021	Ye
1	2	Rank	Synthesize, arrange, & double-check ranking, & analyze interest of researchers & article quality about mobile learning published in high-ranking journals	Ra
1	3	Country	Synthesize of countries conducting research & publishing articles & from there, analysis of level of interest in topic of mobile learning between countries	Co
1	4	Educational level	Synthesize & analyze educational level of participants in articles	EL
2	5	Research aims	Synthesize & analyze research purpose of selected articles	RP
2	6	Research approaches	Synthesize & statistically analyze research approaches in articles	RA
2	7	Research method	Synthesize & statistically analyze research methods in articles	RM

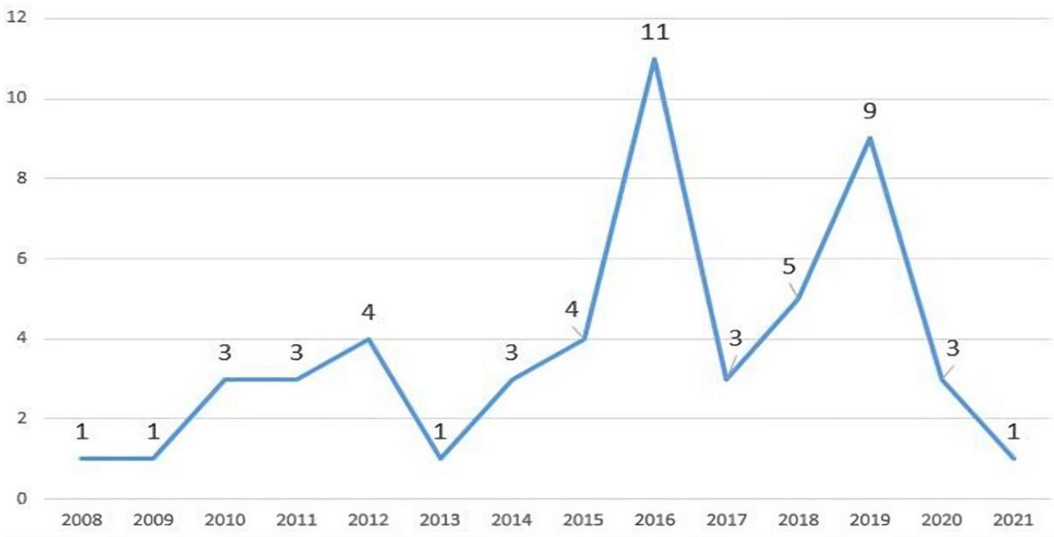


Figure 2. Publication distribution over the years (Source: Authors' own elaboration)

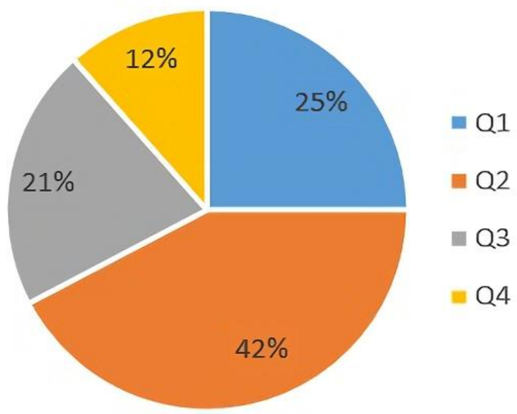


Figure 3. Publication distribution in terms of Scopus quartile ranking (Q1, Q2, Q3, & Q4) (Source: Authors' own elaboration)

members exchange information in order to reach an agreement on the encryption results.

3. **Step 3.** Compose the research's results and discussion.

RESULTS

Distribution of Articles on Mobile Learning in Mathematics Education

Distribution by year

As shown in **Figure 2**, the years 2016 and 2019 have the highest published research, while the years 2008, 2009, 2013, and 2021 have the least. Since the number of articles reported fluctuated over the years, there is no overall trend of changes. However, between the years 2015 and 2021, the fluctuation range is extensive. Moreover, the second half of the period (2008-2021) saw more research than the first.

Distribution by Scopus quartile ranking

In **Figure 3**, most of the studies ranked Q2 (22 articles, 42%), the second is Q1 (13 articles, 25%), the third is Q3 (11 articles, 21%), and the last with just six articles (12%) ranked Q4. This indicates that most of the studies reported are reputable. The data above also demonstrates that top journals are getting more interested in mobile learning research compared to lower-position journals in the same field.

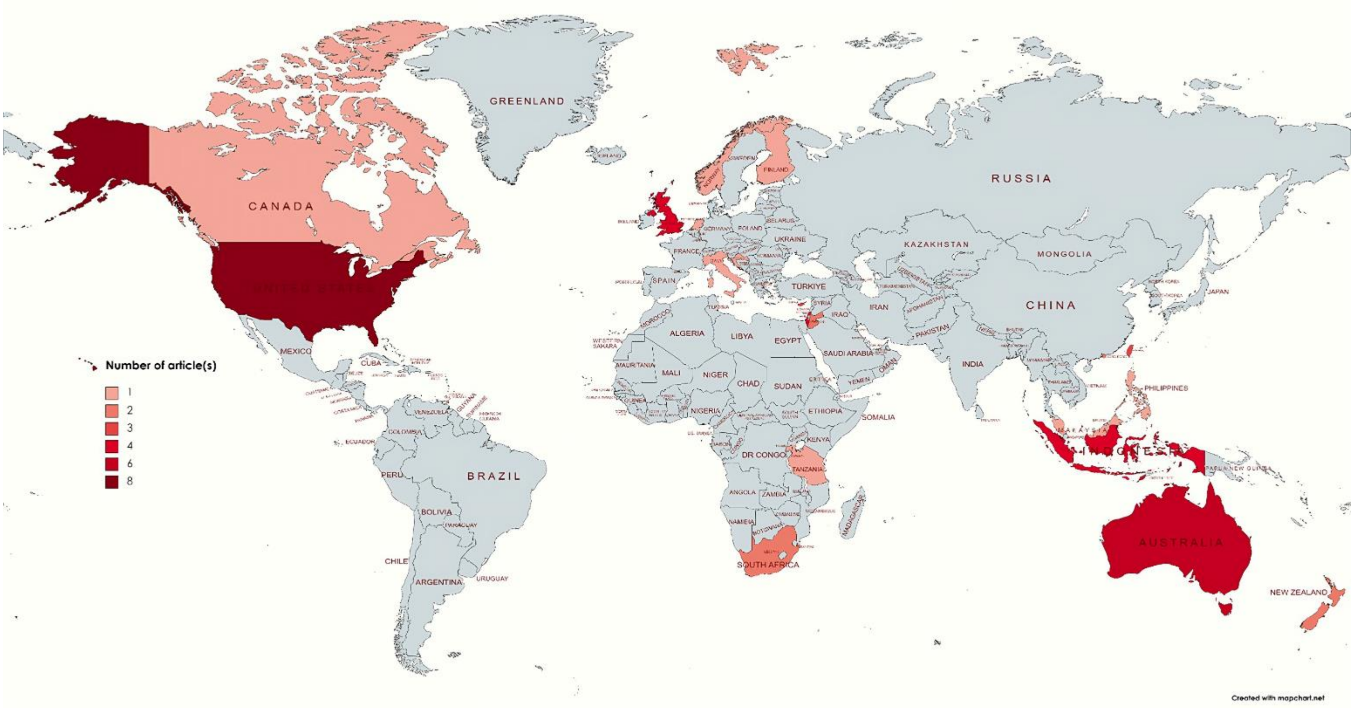


Figure 4. Publication distribution in terms of country (Source: Authors' own elaboration)

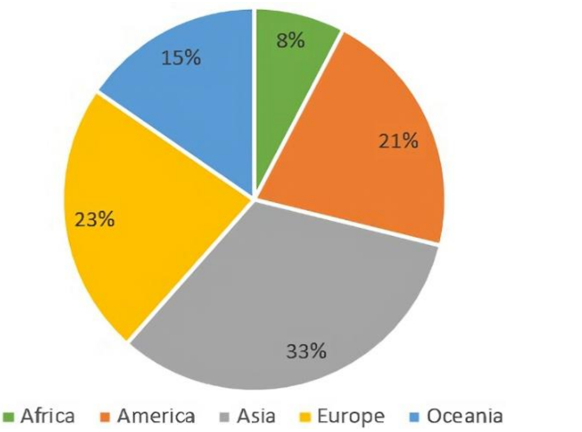


Figure 5. Publication distribution in terms of continent (Source: Authors' own elaboration)

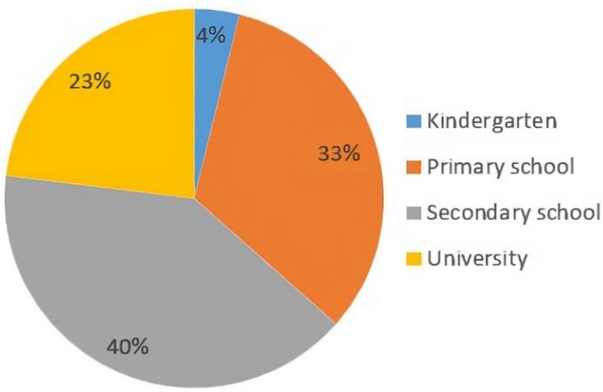


Figure 6. Publication distribution in terms of educational level of learners (Source: Authors' own elaboration)

Geographical distribution

Based on 52 articles published in 30 journals, articles were analyzed to determine their frequency and geographical distribution (**Figure 4**).

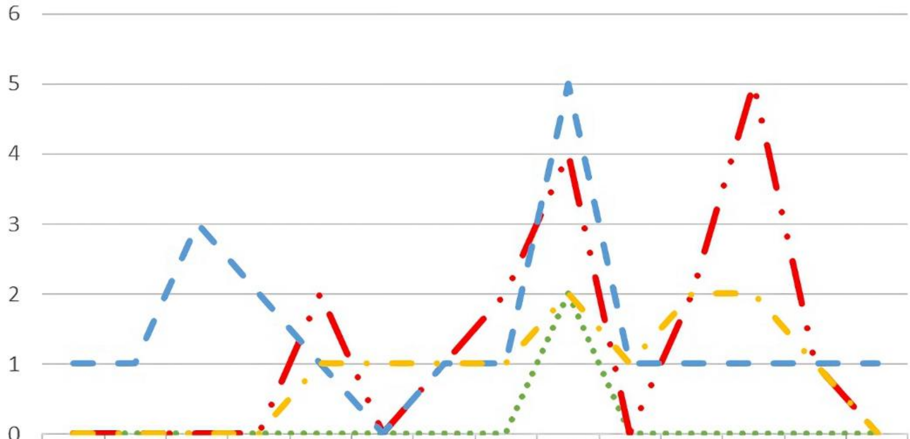
As **Figure 5**, Asia was ranked first in terms of the number of articles published there. Only a few articles came from Africa, ranking it last. More than 50% of articles worldwide were published in Asia (17 articles) and Europe (12 articles). Researchers in America and Oceania published respectively 11 and eight articles. Only four articles had their affiliation address in Africa.

22 countries in five continents were categorized into developed and developing countries. Generally, the number of articles related to mobile learning in developed countries far outweighed the number of developing ones with a 2.5:1 ratio (37:15). It is clear that the United States had the most research papers, and other developed countries finished a close second.

However, there existed a trend in which many developing countries, especially Indonesia, started to get some articles for themselves, which showed that these countries were reducing their science gap and even growing at a pace, where nine developing countries had been included (nearly the same as developed countries). Although the gap is closing, the number of articles published in these developing countries is still small compared to developed countries..

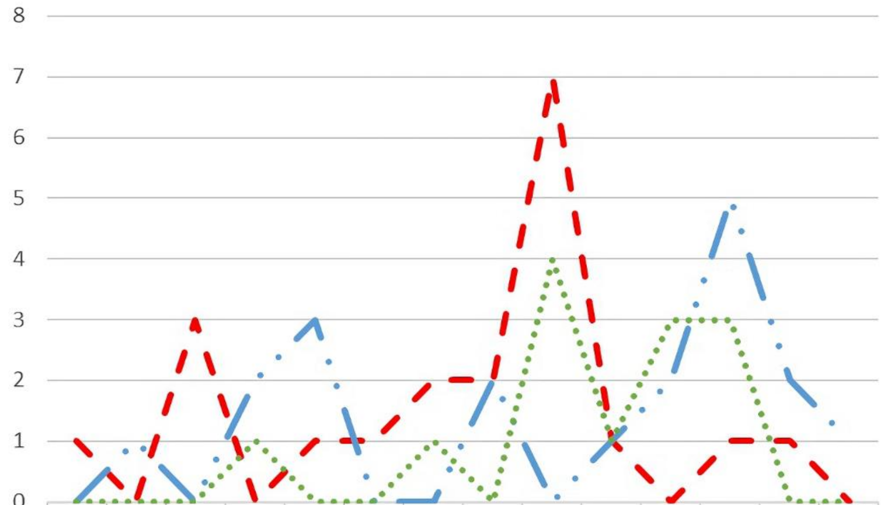
Distribution by educational level

In **Figure 6**, most of the studies were carried out in primary and secondary schools. Secondary-level studies are the largest (21 articles), while the number of kindergarten studies is the lowest (two articles). We also note that besides learners, since 2016, there has been a



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Kindergarten	0	0	0	0	0	0	0	0	2	0	0	0	0	0
Primary school	0	0	0	0	2	0	1	2	4	0	2	5	1	0
Secondary school	1	1	3	2	1	0	1	1	5	1	1	1	1	1
University	0	0	0	0	1	1	1	1	2	1	2	2	1	0

Figure 7. Publication distribution in terms of educational level of learners over the years (Source: Authors' own elaboration)



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Qualitative research	1	0	3	0	1	1	2	2	7	1	0	1	1	0
Quantitative research	0	1	0	2	3	0	0	2	0	1	2	5	2	1
Mixed research	0	0	0	1	0	0	1	0	4	1	3	3	0	0

Figure 8. Publication distribution in terms of research approaches over the years (Source: Authors' own elaboration)

trend of mobile learning research on mathematics teachers, with one or two new articles per year.

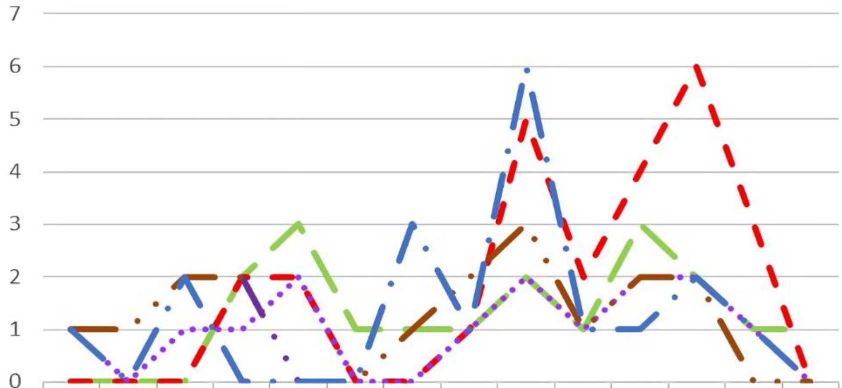
In **Figure 7**, although high school studies have been conducted early, primary school and university studies are starting to dominate in recent years.

Research Purposes

With the study population of 52 articles, the main focus was to investigate the effectiveness of using the app and the curriculum development of mobile learning. However, there existed a trend that some purposes were catching up with the primary focuses, such as technology implementation with 11 articles, student engagement with 10 articles, and evaluating student perceptions and teaching strategies in mobile learning with nine articles (**Table 4**).

Research Approaches and Methods

In **Figure 8**, qualitative research was the primary approach, followed by the quantitative approach, with 20 and 19 articles, respectively. Mixed was relatively the lowest in the list, recorded at 13 studies, a quarter of the total. We also can see that the data of the two qualitative and quantitative methods have been opposites over the



	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Self-report measures	0	0	0	2	3	1	1	1	2	1	3	2	1	1
Performance assessments	0	0	0	2	2	0	0	1	5	2	4	6	3	0
Open-ended questionnaires	1	0	1	1	2	0	0	1	2	1	2	2	1	0
Interviews	1	1	2	2	0	0	1	2	3	1	2	2	0	0
Observations	1	0	2	0	0	0	3	1	6	1	1	2	1	0

Figure 9. Publication distribution in terms of research methods over the years (Source: Authors' own elaboration)

years. In recent years, quantitative and mixed research have become more popular than qualitative research.

As is revealed by **Figure 9**, performance assessment was the most popular method, followed by self-report measures, observations and interviews, and open-ended questionnaires. During these 14 years, the number of usages of observations method and performance assessments method in studies fluctuated slightly before peaking in 2016 and 2019 with six articles. Meanwhile, performance assessments have been a prominent trend in recent years. The other three methods had curbed at a moderate level throughout the period, which showed a consistent trend but was less favored by the researchers.

DISCUSSION

This review presents a valuable synthesis of studies on mobile learning in mathematics education, allowing for a better knowledge of their distribution (by year, ranking, geography, and educational level), purpose, approaches, and method. In addition, this synthesis serves as a resource for future researchers to refer to and expand upon as they add to mobile learning and mathematics knowledge.

RQ1. What Was Their Distribution (e.g., by Year, Ranking, Geography, and Education Level)?

With the Fourth Industrial Revolution, schools are gradually transforming teaching organization methods (Lê et al., 2022). Smart devices are, in turn, introduced into teaching and learning in schools at different levels.

As a result, mobile learning is a well-known and continuing topic of interest. This topic has been studied in different countries, from developed to developing countries (Hwang & Tsai, 2011; Liu et al., 2014). Several articles on this topic are also published in specialized and prestigious journals.

Distribution by year

There are 52 articles selected and used in this study. They were published in the period 2008 to 2021. As shown in **Figure 2**, the number of published articles differs over the years. This is due to independent studies in different places, people, and environments, and it also depends on many other factors. However, mobile learning in mathematics education is still being studied every year at different levels of study, different research directions and countries. This result is similar to the research works of Hwang and Tsai (2011) and Liu et al. (2014), showing the "hotness" of this topic.

Distribution by Scopus quartile ranking

To increase credibility and value, articles need to be submitted and referred to prestigious and quality journals. In this study, the articles ranked Q1 and Q2 have 62% of the total articles selected. This confirms that mobile learning in mathematics education is still a topic for further research and support for teaching.

Geographical distribution

The articles are researched and published in countries in North America, Northern Europe, Southeast Asia, Australia, and Taiwan. Our results are consistent with published subject area reviews of Crompton et al. (2017), Hwang and Tsai (2011), and Liu et al. (2014). They were studied in North America, Northern Europe, Australia, and Taiwan. We added countries in Southeast Asia (Indonesia, Malaysia, and Philippines). But, we selected articles written only in English, lacking publications from developed countries on science education and technology, where English is not popular such as China, Japan, France, and Russia. Thus, this study may not be a complete "picture" of mobile learning in mathematics education.

Distribution by educational level

The results are consistent with the studies of Crompton et al. (2017) and Liu et al. (2014) on the prevalence of publications in elementary and middle schools. A few were studied in preschools. The limitations and adverse psychological and physiological effects of early access to electronic devices by students under six can explain the second. In addition, within the scope of mathematics education, we see the replacement of secondary school studies by itself in primary schools and universities. The revival of technology access (for the first) and researchers' focus on teacher preparation (for the second) in the digital age can both be used to explain this.

RQ2. What Were Their Major Research Purposes, Approaches, and Methods?

The result also revealed that from 2008 to 2021, technological aspects were much more favored in mobile learning than pedagogical ones, consistent with Crompton and Burke (2017), who reported the focus on the evaluation of mobile learning's effectiveness. However, the frequency of curriculum development and teaching strategies in mobile learning with 12 and nine papers was a different finding than the earlier one (Bano et al., 2018), with only one or two articles.

For research approaches, a shift in research approaches from qualitative to quantitative and mixed since 2017. For research methods, the results indicate performance assessments as the dominant method since 2015. This finding results from previous researchers, such as Crompton and Burke (2018), Crompton et al. (2017), Krull and Duart (2017), and Wu et al. (2012) reported that questionnaires or surveys were the most common research method. The use of questionnaires/surveys may come from the division into two types: self-report measures and open-ended questionnaires. Therefore, the division would be better since the data from students' written responses could explicitly reveal the students' experience compared to self-report measures with limitations, such as students' meticulousness and engagement.

CONCLUSION

This systematic literature review provides the scholarly community with a current synthesis of mobile learning in mathematics education settings regarding the year, ranked, geographical, educational level distribution, purposes, approaches, and methods. There were a total of 52 studies included in this meta-analysis. Research on the use of mobile learning was conducted in 22 countries on five continents from 2008 to 2021. Additionally, the most widely cited studies used the three approaches and five methods. Mobile learning contexts have changed from classrooms to real-world contexts with an increasing number of across-context studies. The findings of this systematic review has some results the same as last researchers about distribution by year, ranking, geography, and education level. Beside we also received that more favored in mobile learning than pedagogical, a shift in research approaches and questionnaires or surveys were the most common research method. Therefore, they provide new information for the academic field of mobile learning in mathematics education. Specifically, five new findings have emerged from these data:

(1) learning design and research focused,

(2) mobile learning favored technology, curriculum development, and teaching strategies,

(3) questionnaires or surveys were the most common research method,

(4) the study of the use of mobile devices for mathematics learning is most common in secondary school settings, and

(5) research on mobile learning in mathematics education is geographically diverse.

Author contributions: All authors have sufficiently contributed to the study and agreed with the results and conclusions.

Funding: No funding source is reported for this study.

Ethical statement: Authors stated that the article was approved by the Research Ethics Committee of HCMC University education on 5 July 2022 with decision No. 2208/QD-DHSP.

Declaration of interest: No conflict of interest is declared by authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

REFERENCES

Abidin, Z., Mathrani, A., Hunter, R., & Parsons, D. (2017). Challenges of integrating mobile technology into mathematics instruction in secondary schools: An Indonesian context. *Computers in the Schools, 34*(3), 207-222. https://doi.org/10.1080/07380569.2017.1344056

Acikgul, K., & Sad, S. N. (2020). Mobile technology acceptance scale for learning mathematics: Development, validity, and reliability studies. *International Review of Research in Open and Distance Learning, 21*(4), 161-179. https://doi.org/10.19173/IRRODL.V21I4.4834

Al-Emran, M., Mezhuyev, V., & Kamaludin, A. (2018). Technology acceptance model in mobile learning context: A systematic review. *Computers and Education, 125*, 389-412. https://doi.org/10.1016/j.compedu.2018.06.008

Al-Khateeb, M. A. (2018). The effect of teaching mathematical problems solving through using mobile learning on the seventh grade students' ability to solve them in Jordan. *International Journal of Interactive Mobile Technologies, 12*(3), 178-191. https://doi.org/10.3991/ijim.v12i3.8713

Bano, M., Zowghi, D., Kearney, M., Schuck, S., & Aubusson, P. (2018). Mobile learning for science and mathematics school education: A systematic review of empirical evidence. *Computers & Education, 121*, 30-58. https://doi.org/10.1016/j.compedu.2018.02.006

Borba, M. C., Askar, P., Engelbrecht, J., Gadanidis, G., Llinares, S., & Aguilar, M. S. (2016). Blended learning, e-learning and mobile learning in mathematics education. *ZDM-Mathematics Education, 48*(5), 589-610. https://doi.org/10.1007/s11858-016-0798-4

Chung, C. J., Hwang, G. J., & Lai, C. L. (2019). A review of experimental mobile learning research in 2010-2016 based on the activity theory framework. *Computers and Education, 129*, 1-13. https://doi.org/10.1016/j.compedu.2018.10.010

Criollo-C, S., Guerrero-Arias, A., Jaramillo-Alcázar, Á., & Luján-Mora, S. (2021). Mobile learning technologies for education: Benefits and pending issues. *Applied Sciences (Switzerland), 11*(9), 4111. https://doi.org/10.3390/app11094111

Crompton, H., & Burke, D. (2017). Research trends in the use of mobile learning in mathematics. In *Blended learning: Concepts, methodologies, tools, and applications* (pp. 2090-2104). IGI Global. https://doi.org/10.4018/978-1-5225-0783-3.ch101

Crompton, H., & Burke, D. (2018). The use of mobile learning in higher education: A systematic review. *Computers and Education, 123*, 53-64. https://doi.org/10.1016/j.compedu.2018.04.007

Crompton, H., & Burke, D. (2020). Mobile learning and pedagogical opportunities: A configurative systematic review of preK-12 research using the SAMR framework. *Computers and Education, 156*, 103945. https://doi.org/10.1016/j.compedu.2020.103945

Crompton, H., Burke, D., & Gregory, K. H. (2017). The use of mobile learning in PK-12 education: A systematic review. *Computers and Education, 110*, 51-63.https://doi.org/10.1016/j.compedu.2017.03.013

Crompton, H., Burke, D., Gregory, K. H., & Gräbe, C. (2016). The use of mobile learning in science: A systematic review. *Journal of Science Education and Technology, 25*(2), 149-160. https://doi.org/10.1007/s10956-015-9597-x

Drigas, A. S., & Pappas, M. A. (2015). A review of mobile learning applications for mathematics. *International Journal of Interactive Mobile Technologies, 9*(3), 18-23. https://doi.org/10.3991/ijim.v9i3.4420

Fabian, K., & Topping, K. J. (2019). Putting "mobile" into mathematics: Results of a randomized controlled trial. *Contemporary Educational Psychology, 59*, 1-12. https://doi.org/10.1016/j.cedpsych.2019.101783

Fabian, K., Topping, K. J., & Barron, I. G. (2018). Using mobile technologies for mathematics: effects on student attitudes and achievement. *Educational Technology Research and Development, 66*(5), 1119-1139. https://doi.org/10.1007/s11423-018-9580-3

Grant, M. M. (2019). Difficulties in defining mobile learning: analysis, design characteristics, and implications. *Educational Technology Research and Development, 67*(2), 361-388. https://doi.org/10.1007/s11423-018-09641-4

Hwang, G. J., & Tsai, C. C. (2011). Research trends in mobile and ubiquitous learning: A review of publications in selected journals from 2001 to 2010. *British Journal of Educational Technology, 42*(4), E65-E70. https://doi.org/10.1111/j.1467-8535.2011.01183.x

ITU. (2021). Measuring digital development-Facts and figures 2021. *International Telecommunication Union*. https://www.itu.int/en/ITU-D/Statistics/Documents/facts/FactsFigures2021.pdf

Krull, G., & Duart, J. M. (2017). Research trends in mobile learning in higher education: A systematic review of articles (2011-2015). *International Review of Research in Open and Distance Learning, 18*(7), 1-23. https://doi.org/10.19173/irrodl.v18i7.2893

Kumar, B. A., & Mohite, P. (2017). Usability of mobile learning applications: A systematic literature review. *Journal of Computers in Education, 5*(1), 1-17. https://doi.org/10.1007/s40692-017-0093-6

Lai, C. L. (2019). Trends of mobile learning: A review of the top 100 highly cited papers. *British Journal of Educational Technology, 51*(3), 721-742. https://doi.org/10.1111/bjet.12884

Larkin, K., & Calder, N. (2016). Mathematics education and mobile technologies. *Mathematics Education Research Journal, 28*(1), 1-7. https://doi.org/10.1007/s13394-015-0167-6

Lê, S. H., Trần, T. A., Trương, H. Đ., Nguyễn, H. Q., & Nguyễn, T. A. (2022). Propose a smart classroom model to enhance education experience in Industrial Revolution 4.0 era. *VNUHCM Journal of Economics, Business and Law, 6*(2), 2800-2808.

Liu, M., Scordino, R., Geurtz, R., Navarrete, C., Ko, Y., & Lim, M. (2014). A look at research on mobile learning in K-12 education from 2007 to the present. *Journal of Research on Technology in Education, 46*(4), 325-372. https://doi.org/10.1080/15391523.2014.925681

Meletiou-Mavrotheris, M., Paparistodemou, E., & Christou, C. M. (2019). Integrating mobile devices in the mathematics curriculum: A case study of a primary school in Cyprus. *International Journal of Mobile and Blended Learning, 11*(3), 19-37. https://doi.org/10.4018/IJMBL.2019070102

Pimmer, C., Mateescu, M., & Gröhbiel, U. (2016). Mobile and ubiquitous learning in higher education settings. A systematic review of empirical studies. *Computers in Human Behavior, 63*, 490-501. https://doi.org/10.1016/j.chb.2016.05.057

Qureshi, M. I., Khan, N., Ahmad Hassan Gillani, S. M., & Raza, H. (2020). A systematic review of past decade of mobile learning: What we learned and where to go. *International Journal of Interactive Mobile Technologies, 14*(6), 67-81. https://doi.org/10.3991/IJIM.V14I06.13479

Sung, Y. T., Chang, K. E., & Liu, T. C. (2016). The effects of integrating mobile devices with teaching and learning on students' learning performance: A meta-analysis and research synthesis. *Computers and Education, 94*, 252-275. https://doi.org/10.1016/j.compedu.2015.11.008

Sung, Y. T., Lee, H. Y., Yang, J. M., & Chang, K. E. (2019). The quality of experimental designs in mobile learning research: A systemic review and self-improvement tool. *Educational Research Review, 28*, 100279. https://doi.org/10.1016/j.edurev.2019.05.001

UNESCO. (2013). Policy guidelines for mobile learning. *United Nations Educational Scientific and Cultural Organization*. https://unesdoc.unesco.org/ark:/48223/pf0000219641

Wang, W., Schmidt-Crawford, D., & Jin, Y. (2018). Preservice teachers' TPACK development: A review of literature. *Journal of Digital Learning in Teacher Education, 34*(4), 234-258. https://doi.org/10.1080/21532974.2018.1498039

Wingkvist, A., & Ericsson, M. (2011). A survey of research methods and purposes in mobile learning. *International Journal of Mobile and Blended Learning, 3*(1), 1-17. https://doi.org/10.4018/jmbl.2011010101

Wu, W. H., Jim Wu, Y. C., Chen, C. Y., Kao, H. Y., Lin, C. H., & Huang, S. H. (2012). Review of trends from mobile learning studies: A meta-analysis. *Computers and Education, 59*(2), 817-827. https://doi.org/10.1016/j.compedu.2012.03.016

https://www.ejmste.com