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Research Trends in the Use of Mobile Learning in Mathematics

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ABSTRACT

The use of mobile learning in education is growing at an exponential rate. To best understand how mobile learning is being used, it is crucial to gain a collective understanding of the research that has taken place. This research was a systematic review of 36 studies in mobile learning in mathematics from the year 2000 onward. Eight new findings emerged: (1) The primary purpose of most studies was to focus on evaluating mobile learning. (2) Case studies and experimental design were the main research methods. (3) Most studies report positive learning outcomes; (4) Mobile phones were the mobile device used most often. (5) Elementary school settings were the most common research context. (6) The majority of researchers did not identify a specific mathematical concept being studied. (7) The majority of the studies took place in formal educational contexts; and (8) research on mobile learning in mathematics is geographically diverse.

Keywords: *Math, Mathematics, Mobile Devices, Mobile Learning, Research, Pedagogies, Synthesis*

There is a growing interest in exploiting the affordances of mobile devices for educational purposes (Ally, Prieto-Blazquez, 2014; Kukulska-Hulme, Sharples, Milrad, Arnedillo-Sánchez, & Vavoula, 2009). Empirical evidence suggests that teachers are interested in using mobile devices in their classrooms (Hodges and Prater, 2013) and in the United States (US), seven in ten elementary students (71%), two-thirds of middle school students (67%) and over half (56) of high school students state that they would like to use mobile devices for learning (Pearson Education 2014). Nonetheless, few teachers are choosing to use mobile devices within formal and informal classroom settings (Groff & Mouza, 2008; Levin & Wadmany, 2008). This can be attributed to a lack of teacher training and understanding (Crompton, Olszewski, & Bielefeldt, 2015; Cheon et al. 2012) and a lack of pre-service and in-service teacher training in how to use mobile devices for educational purposes (Goktas, Yildirim, & Yildirim, 2009).

To support best practices in the use of mobile learning it is important to provide stakeholders, such as policy makers, teachers, and students, information and examples of how mobile learning can be used effectively. Past researchers have analyzed mobile learning studies with the focus on the learner (viz., Capretz & Alrasheedi, 2013; Wu, Wu, Chen, Kao, Lin, & Huang,

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2012) and on technologies (viz., Pereira & Rodrigues, 2013). Although these reviews provide a rich source of information on mobile learning, they do not provide data on a particular subject area. Therefore, these reviews can only be used as generalizable information across all subjects which is not helpful for those looking at a particular subject area.

The purpose of this study is to aggregate and explore empirical evidence of the use of mobile learning in mathematics. This is the first review to provide a comprehensive collection of mobile learning and mathematical studies to initiate an evidence -based discussion on mobile learning in mathematics teaching.

BACKGROUND

As the field of mobile learning has developed and devices have advanced, there have been a number of ephemeral definitions of mobile learning. Earlier definitions have named a particular device which quickly becomes dated, or they have been technocentric (Crompton, 2013a). Nonetheless, trends have emerged from these definitions that highlight the four central constructs of mobile learning as pedagogy, technological devices, context, and social interactions (Crompton, 2013b). Aligned to these constructs, Sharples, Taylor, and Vavoula (2007) define mobile learning as “the processes of coming to know through conversations across multiple contexts amongst people and personal interactive technologies” (p. 224).

Using these constructs, (Crompton, 2013b) defined mobile learning as “learning across multiple contexts, through social and content interactions, using personal electronic devices” (p. 4). This is the definition selected for this article.

Determining which devices are included in m-learning has also been a topic of debate among scholars (Traxler, 2009). For this study, Crompton’s (2013a) criteria have been used (see p. 48) to define what qualifies as a mobile device. She proffers that the device must be portable and incorporate a prompt on-off button. The latter is extremely problematic with traditional laptops, as they take a while to start and they are typically not left on standby mode to use quickly. For this reason, laptops were not included as mobile devices in this study.

As mobile learning is a relatively new field of study, there is a paucity of studies that collectively review and analyze mobile learning research. The major reviews of mobile learning in education include a critical analysis of mobile learning projects conducted by Frohberg, Goth, and Schwabe (2009) as they focused on six criteria: context, control, tools, communication, subject, and objective. Using a framework to systematically analyze and position mobile learning projects, Frohberg et al. reported screening 1469 publications to finally analyze 102 publications. Frohberg et al. found that although mobile devices were primarily for communication, they found few connections to the research regarding communication or collaboration. The researchers also found that the majority of the studies supported novice learners.

Hung and Zhang (2012) conducted a study of mobile learning research trends from 2003 to 2008. Text mining techniques were used to provide basic bibliometric statistics, trends in frequency of topics, predominance of topics by country, and preference for each topic by journal. The researchers found that: 1) mobile learning articles increased from eight in 2003 to 36 in 2008; 2) effectiveness, evaluation, and personalized systems were the most popular area of study; and 3) Taiwan conducted the most mobile learning studies.

Hwang and Tsai (2011) conducted a study of research trends in mobile and ubiquitous learning from selected journals from 2001 to 2010. They found the number of articles published from 2005 to 2010 was nearly four times that of from 2001 to 2005. The sample groups selected for study ranked as follows: higher education (59), elementary students (41), high school students

(17). Only a few studies selected teachers (6) and working adults (6) as the research sample. Their research found that most studies did not involve any learning domain, but rather, they mainly focused on investigation of motivation, perception and attitudes of students towards mobile learning. Contributing countries numbered 23 with Taiwan having the highest number of publications (51).

Liu et. al. (2014) examined data-based studies on mobile learning in K-12 from 2007 to the present. They found in 63 studies from 15 refereed journals that research was primarily exploratory in nature and focused on understanding the educational affordances of using mobile devices in instructional practices.

A survey of 114 papers from mLearn 2005, 2007 and 2008 conducted by Wingkvist and Ericsson (2011) investigated and compared the research methods and research purposes of these papers. Their results showed an even distribution in respect to research methods, with only basic research being under-represented. In terms of research purposes, describing was the most frequent and was used in more than half the papers, followed by one-fourth developing papers and one-seventh understanding. Evaluating was represented only within one-fortieth of the total number of papers investigated. These authors stated that a challenge for mobile learning research is to stop, turn around, and reflect over the research results in order to avoid already known pitfalls. They also stated that a head start is given if research is built on previous research instead of reinventing the wheel every time a new mobile learning initiative begins. The preceding studies have provided a big picture look at how mobile learning is occurring in education. However, these studies do not provide any valuable insights into specific content areas.

PURPOSE

The purpose of this study is to conduct a systematic review of mobile learning as it relates to mathematics. The researchers systematically reviewed the literature as a way of summarizing the research evidence to gain an understanding of the breadth, purpose and extent of the research activity in the use of mobile learning in mathematics. The findings of this study could provide the head start suggested by Wingkvist and Ericsson (2011) upon which future research is based regarding studies of mobile learning in mathematics. This study is also beneficial to researchers, funders, educational leaders, policy makers, and other stakeholders as the current use of mobile learning in mathematics is explained and clarified. The results can help in making decisions about how to allocate necessary resources and help in making plans to support further research and applications.

Three questions are used to drive this systematic review of mobile learning in mathematics:

1. In studies involving mobile learning and mathematics, what were the major research purposes, methodologies, and outcomes?
2. In studies involving mobile learning and mathematics, what were the mathematical concepts, educational levels, and educational contexts?
3. In studies involving mobile learning and mathematics, what were the mobile devices used and the geographical distribution of the studies?

METHOD

In this study, the researchers conducted a systematic review to provide an unbiased synthesis and interpretation of the findings in a balanced and impartial way (Hemingway & Brereton, 2009). A systematic review is the art and science of identifying, selecting, and synthesizing primary research studies to provide a comprehensive and trustworthy picture of the topic being studied (Oakley, 2012). The researchers used aggregated quantitative data and qualitative coding to analyze and interpret the results.

Search Strategy

This systematic review was based on established PRISMA (Liberati et al., 2009) principles. The literature search was conducted using both an electronic search of databases and manual searches of specific journals to insure a more exhaustive scope. Only peer-reviewed articles published in academic journals were included. These data were retrieved from an electronic search of educational databases ERIC, EBSCOHOST, ProQuest, Wiley International Science, Elsevier Direct, JSTOR, and Sage Journal On-line. Manual searches were conducted journals that include a focus on mobile learning, specifically the *International Journal of Emerging Technologies in Learning*, *ELEED, Journal of Mobile Teaching, IEEE,* and the *International Journal of Mobile and Blended Learning*.

In both the electronic and manual searches, the following search terms were used: "Mathematics," "Math," and "Maths," with "mobile learning," "m-learning," "hand-held," "tablets," "iPad," Ubiquitous learning," "wireless learning," "location-aware," context-aware," "situated learning", "game-based learning", and "digital learning." These search terms were used as they are the terms most frequently chosen when describing mobile learning.

Study Selection

The initial search resulted in 19,267 articles. This large number uncovered that the search terms were being interpreted broadly by the search engines. A review of the articles revealed that the changing meaning of terms over time resulted in inaccurate findings. To ensure that the search was revealing studies that related to the current use of mobile devices, the dates of the search were reduced by decade until articles that related to the current use of mobile devices appeared. This resulted in the decision to include studies from 2000 onwards.

Inclusion/Exclusion Criteria

The inclusion and exclusion criteria can be found in Table 1. To be included in this systematic review, each study had to meet all the inclusion and exclusion criteria.

The search from the year 2000 revealed a total of 830 articles. After removing duplicates and those that did not meet the initial criteria to include mobile learning and mathematics, 63 studies remained. Each of the articles was checked against the inclusion and exclusion criteria by two independent researchers. The inter-rater coding agreement was 94.8%. Articles in dispute were discussed, further reviewed, and were either accepted or removed. A total of 36 articles met all of the criteria listed in Table 1. A diagrammatic representation of the literature search and review process can be seen in Figure 1.

Table 1. Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Learners use mobile devices	The mobile device must not be a laptop
Mathematics is a primary focus	The mobile device must not be Netbooks
Mobile devices are used for learning	The mobile device must not be calculators (that just calculate
Article available to the public	
Peer reviewed and published in a journal	

Analysis Framework

The research questions framed the eight features that were coded for analysis: 1) research purpose, 2) research method (e.g. observations, case study), 3) learning outcomes (i.e. positive, negative, neither, and other), 4) mathematical concepts based on the National Council of Mathematics (NCTM, 2014) Standards, 5) educational levels (e.g. pre-k (2-4 years old), elementary (5-11 years old), middle (11-14 years old), high school (14-18 years old), higher education (18+ years old), and special education), 6) educational context (i.e. formal, informal, and non-formal), 7) mobile devices (e.g. mobile phones, tablets), and 8) countries of study.

The research purposes were classified as one of two types: 1) student-dominant with device-minor, 2) device-dominant with student-minor. Type one focuses on student and then the device (e.g. the researcher wants to focus on the student and see how the device influences learning.) Type two focuses on the device before the student (e.g. the development of a mobile application).

The learning outcomes are coded as positive, negative, neutral, and other. Studies were coded positive for improved student learning, neutral for findings that primarily did not have a positive or negative impact on student learning and negative if students' learning was lessened due to using a mobile device. The other code was assigned if the results did not focus on student learning. For example, the development of guidelines would be coded as other.

The educational contexts of the studies were coded following Crompton's (2013b) categories of educational context; formal, non-formal, and informal. Formal is intended learning in a typical educational setting (e.g. a taught class in a school), non-formal is non-intended learning (e.g. determining sale percentages in a shop), and informal learning, which is intended learning in an atypical setting (e.g. a lesson taking place in a playground).

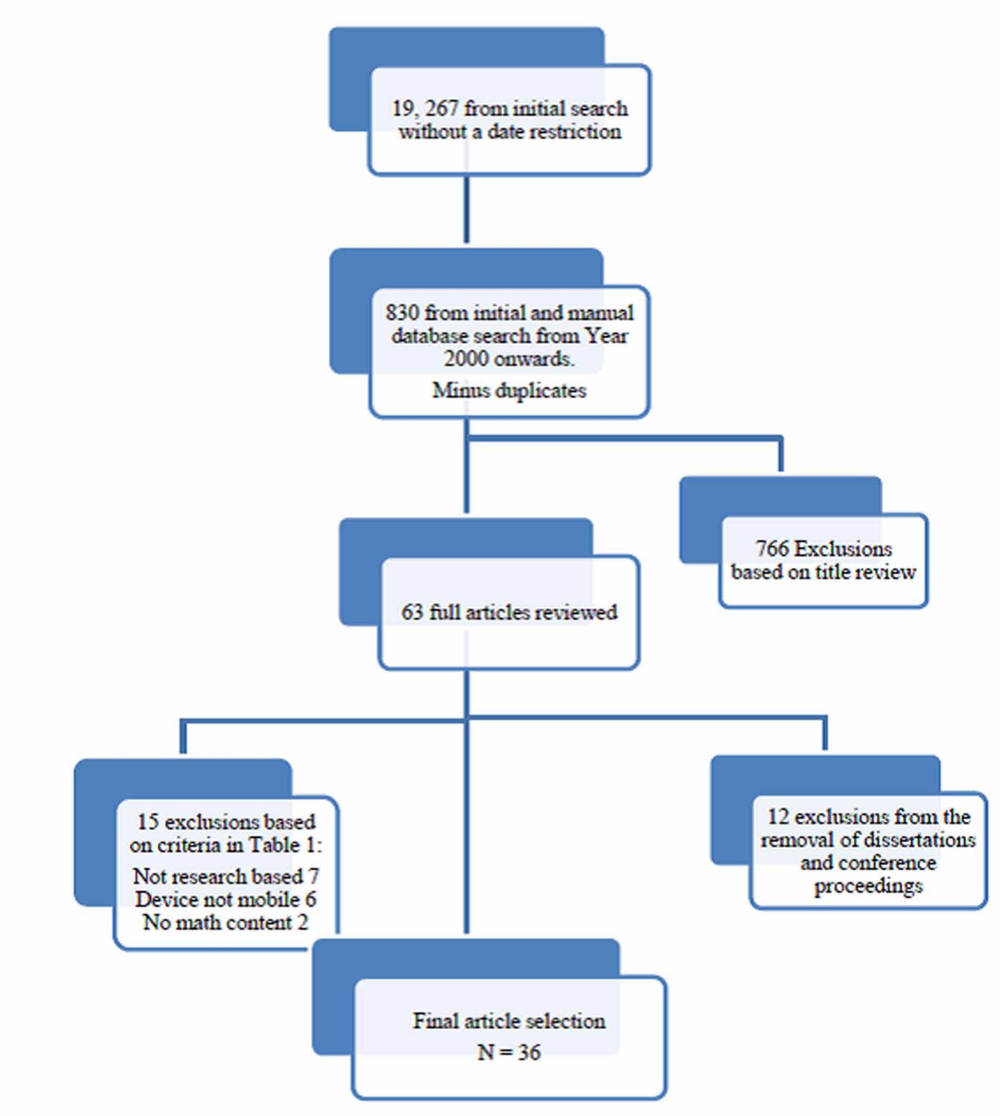
RESULTS

Research Question One: What were the Major Research Purposes, Methods and Outcomes?

Research Purposes

Each of the studies was classified into one of three categories aligned to the research purpose; (1) evaluating the effects of mobile learning, (2) designing a mobile system for learning or (3) investigating the affective domain during mobile learning. As seen in Figure 2, evaluating the effects of mobile learning was the most common research purpose (69%), followed by design-

Figure 1. A diagrammatic representation of the literature search and review process



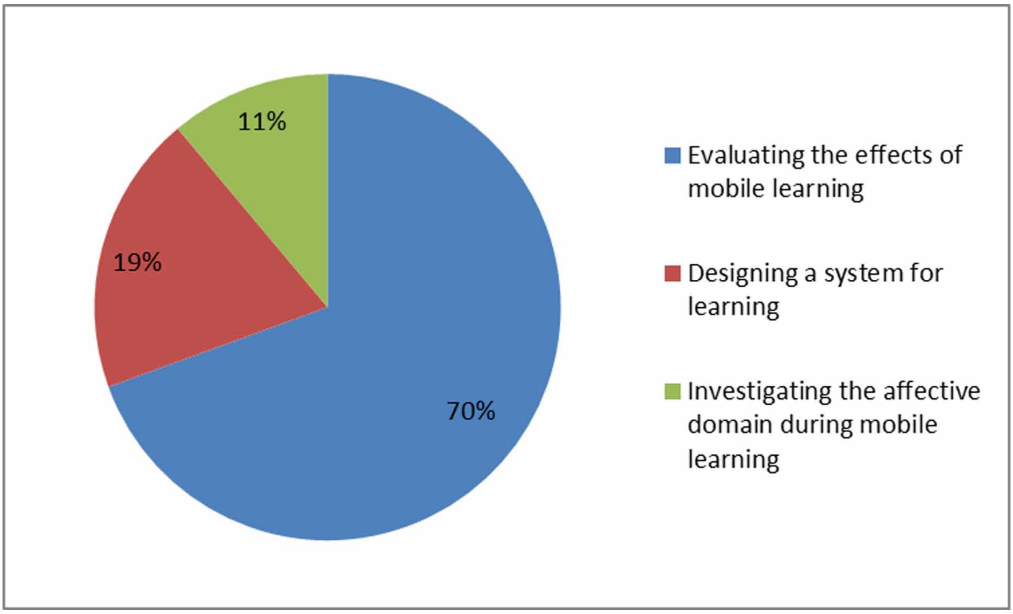
ing a mobile system for learning (19%) and investigating the affective domain during mobile learning (11%).

Research Methods

As seen in Table 2, type one studies which focused primarily on the student comprised 81% of the studies. The remaining studies were type two, which focused primarily on the device.

Table 2 indicates that for purpose 1, (evaluating the effects of mobile learning) researchers primarily relied on case studies followed by experimental designs. For research purpose two

Figure 2. Mobile learning studies by research purposes



(designing a mobile system for learning) and three (investigating the affective domain during mobile learning), there was no dominant methodology.

Research Outcomes

Figure 3 indicates that 71% of the studies reported positive learning outcomes. Ten percent reported neutral learning outcomes. No studies reported a negative learning outcome and 18% reported outcomes that were not related to effects on student learning.

Research Question Two: What were the Mathematical Concepts, Educational Levels, and Educational Contexts?

Mathematical Concepts

The majority of the studies (64%) did not indicate the specific NCTM (2014) standard being taught. Algebra and Numbers and Operations were the standards most often stated (17%) followed by Geometry (2%). Data Analysis and Probability, Measurement and Process were not represented in any of the studies. Figure 4 displays the NCTM mathematical concepts with the academic level of the students.

Educational Levels

Elementary schools were most often the setting of the research studies (34%), followed by middle schools (29%). High schools (21%), higher education (13%) and special education (2%) were the remaining settings. No studies reported Pre-K settings.

Table 2. Study Methodology

Student-dominant with device minor		Device-dominant with student minor
Purpose one	Purpose three	Purpose two
Case study (8)	Survey (1)	Quasi-experimental (1)
Survey (4)	Grounded theory (1)	Experimental control group (1)
Experimental (4)	Constant comparison (1)	Qualitative(1) Questionnaire, interviews observations
Mixed methods (2)	Pre-Post tests (1)	Design-based research (1)
Quasi-experimental (2		Test scores (1)
Comparison linear modeling (2)		Case study (1)
Design-based research (1)		Mixed Methods (1) Videos Field Notes Interviews
Alternative treatments design (1)		
Quantitative t-test (1)		
Test scores (1)		
Grounded theory (1)		
Qualitative coding (1)		

Note: The number in brackets is the number of studies that specified using that methodology (or type of data collection).

Figure 3. Research outcomes

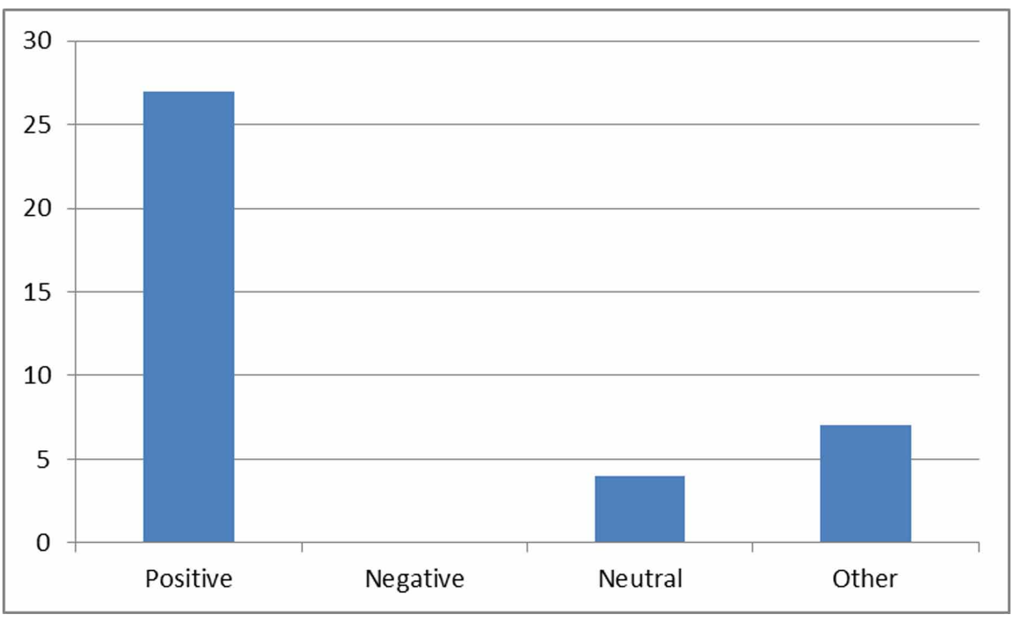
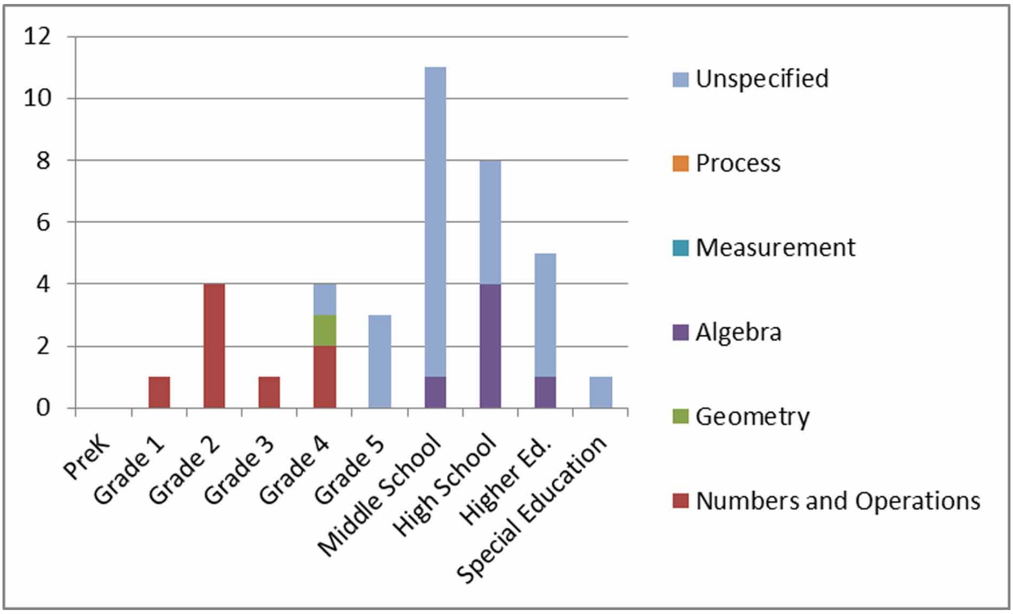


Figure 4. Educational concepts and levels



Types of Educational Contexts

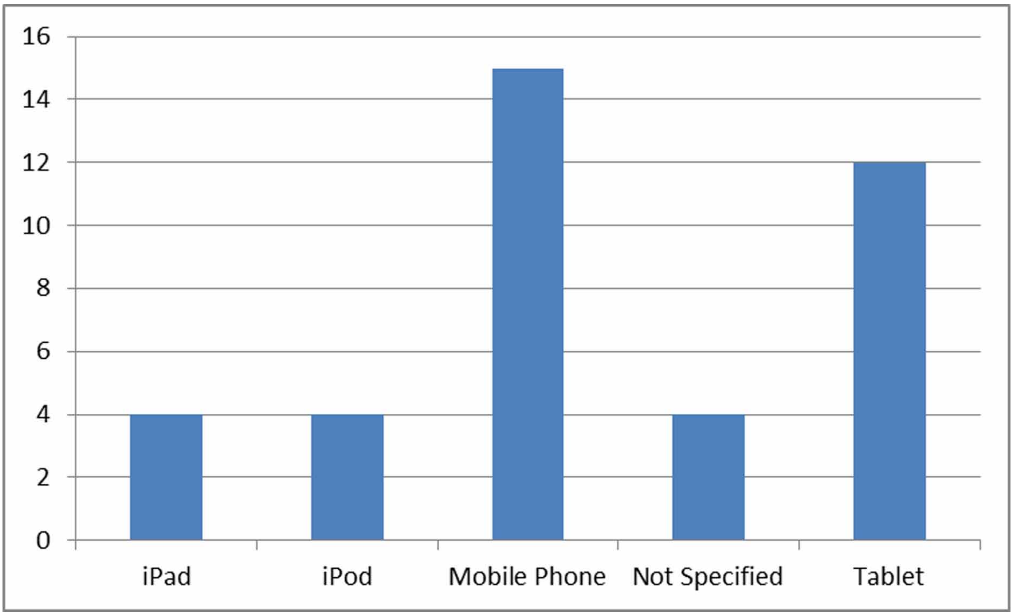
Figure 5 reveals that the majority of the studies took place in formal educational context (83%), while the remainder (17%) took place in informal contexts. Four of the six studies conducted within informal settings took place with middle school students. Three of those studies concentrated on measurement and the fourth one concentrated on algebra. One of the studies took place with elementary students studying geometry. The final study was in higher education with no specific math content given. None of the studies specifically identified the informal settings, but rather described the settings as outdoor activities in a real life environment, a physical environment, an out of school environment and observed phenomena. No studies were conducted in non-formal contexts.

Research Question Three: What were the Types of Mobile Devices and Geographical Distribution of Studies?

Types of Mobile Devices

Mobile phones were reported as the most frequently used mobile device (38%). Tablets (31%) were next in frequency followed by iPads (10%) and iPods (10%). Not all studies specified a type of mobile device (10%) and just used the term mobile device. This information can be seen in Figure 5. The terms used to describe the type of mobile device were those used by the specific research studies.

Figure 5. Types of mobile devices



Countries of Study

The United States was the country with the highest number of studies (34%) followed by Israel (20%) and Taiwan (10%) and the Caribbean (8%). The United Kingdom and Chile, each comprised 4%. Spain, The United Arab Emirates, Sweden, Australia, Nigeria, and India each comprised 3%.

DISCUSSION

This systematic review provides a valuable synthesis of studies on mobile learning in mathematics providing an understanding of the breadth, purpose and extent of the research activity in this area. This synthesis provides a place for future researchers to reference and build upon as they add to the knowledge regarding mobile learning and mathematics. Mathematics educators can find this synthesis a valuable resource regarding how mobile learning has been integrated into mathematics classrooms. They can use this knowledge to replicate or expand mobile learning practices in their own classrooms. In the following section, each research question is delineated with an analysis of the results.

Research Question One: What were the Major Research Purposes, Methods and Outcomes?

Of the 36 studies, 69% of the researchers stated that evaluating the effectiveness of mobile learning in mathematics was the primary research purpose. This finding is similar to the result found by Wu, et al. (2012) and Vogel, Vogel, Canon-Bowers, Muse, & Wright (2006) who both studied mobile learning in general. The second most frequently-cited research purpose was mobile learning system design. This also was found in the Wu, Wu, et al. (2012) study. As the use of mobile learning has become more common in educational settings, research in the effectiveness of mobile learning in relation to student learning outcomes grows in importance. Although our review revealed that 69% of the studies were focused primarily on effectiveness, the total number of studies is only 25. Future investigations focused on the effectiveness of the use of mobile learning in mathematics would add to the robustness of this research.

Case studies were the primary research method (9) followed by experimental design (8). The findings reveal a wide variance across the research methodologies. In an analysis of the various types of studies qualitative and quantitative methodologies were equally represented. This is an interesting difference from the findings of Wu, et al. (2012). In their review of mobile learning across all subjects they found quantitative methods to be the dominant methodology used. It is valuable to explore mobile learning in mathematics with various research methodologies. This will avoid having gaps in the academic knowledge in these research areas.

From the 36 studies, 27 presented positive learning outcomes. This finding correlates with the findings of Wu, Hwang, Su, & Huang (2012). There are a number of words of caution that need to be stated here. First, it can be argued that less research is published with a negative outcome than those that are positive. More importantly, however, is the need to evaluate the quality of the research studies to determine the rigor of the validity and reliability of the research being done. It was beyond the scope of this systematic review to do so. As researchers, we recommend that this could be a future avenue of study that would add value to the research. Research areas to analyze could include sample size, comparisons between mobile learning and other learning methodologies and different student populations.

Research Question Two: What were the Mathematical Concepts, Educational Levels, and Educational Contexts?

Although the mathematic concepts were not always identified, typically a grade level was presented. This lack of identification of the mathematical concept could mean that the authors of the research manuscripts thought that the reader understood what is expected of students at that grade level. It could also lead to the inference that mathematics was not the focus of the study but rather the focus was on the technologies used. Furthermore, it could be that the researchers were not confining the study to a particular strand in mathematics, but developing skills and abilities across all areas in mathematics. The researchers of this study believe that the concept being taught should be stated in a manuscript to better help the reader gain a full understanding of the context of the study. This would also ensure that the study could be applied by practitioners and replicated by researchers in other settings.

Mobile learning is most frequently used in elementary mathematics settings (34%) followed by middle school (29%). This is an interesting difference from the findings of Wu, Wu, et al. (2012). In their literature review on mobile learning across all subjects, they found higher education to be the most frequent context for mobile learning studies. However, when the focus is on mathematics, the research takes place primarily in an elementary setting. With that being said, when the numbers across K-12 are reviewed, the analysis reveals a fairly equal distribution—34% (elementary), 29% (middle), and 21% (high school). This could lead to the conclusion that the use of mobile devices in K-12 settings is happening at all educational levels.

The majority of the studies took place in formal educational contexts (83%), while the remainder (17%) took place in informal contexts. No studies were conducted in non-formal contexts where learning was not intended or planned for. Although mobile devices allow learners to be more mobile, the majority of the research thus far has been within a typical classroom setting.

Of the studies that took place outside the classroom, there did not appear to be a particular outdoor location chosen for the studies. This fits with the philosophy that students should mathematize the world in which they live and not just connect mathematics with a particular location. Learning in the real world is a natural space for mathematics. The portability of these devices makes this opportunity a distinct possibility.

Half of the studies that took place in the outdoor locations were connected with middle school measurement. This subject and age group were most likely chosen due to the ease in connecting these concepts to the real-world. In addition, as the students are gaining an emerging understanding of measurement, it is perhaps the best time to contextualize the concept before making the transition to decontextualized learning within the classroom and seamlessly between the two (contextualized and decontextualized). However, it would be interesting how mobile learning can be used to explore other mathematical concepts with older students in both contextualized and decontextualized settings.

Research Question Three: What were the Types of Mobile Devices and Geographical Distribution of Studies?

Mobile phones were the device listed most often as the mobile learning tool used in the mathematics studies and accounted for 38% of the devices identified. However, the generic term, tablet, appears in 31% of the studies. The iPad (10%) and the iPod Touch (10%) combined reached 20% and 18% of the researchers do not identify a specific device. As ownership of cell phones is more than 100 percent in many countries (Tsinakos, 2013), it is not a surprise that this technology emerged as the most identified mobile tool for learning mathematics. Lack of a specifically favored device indicates that the type of device used may not be important. The lack of importance regarding a specific device helps to support the growing increase in BYOD (Bring Your Own Device) programs (Johnson et. al., 2014). An analysis of the 36 research studies indicated that 33% of the studies were conducted in the United States. However, studies included in this analysis represented 12 different countries found on five different continents—North America, South America, Europe, Asia and Africa. This is similar to the findings of Hung and Zhang, (2012) who studied mobile learning across the subjects. However, they found Taiwan as the most common country followed by the USA. The growing global access to mobile technologies has made the use of mobile devices in educational settings more prevalent around the world and it is appropriate that the research would be world-wide. This research interest on a global level regarding the use of mobile learning in mathematics can provide opportunities for researchers to share their research across countries and cultures, enriching our academic understanding of mobile learning in a variety of contexts.

IDENTIFIED GAPS AND FUTURE RESEARCH

Six gaps in the research were identified in this systematic review. First, from the year 2000 onward, only 36 studies have been published in peer reviewed journals on the topic of mobile learning in mathematics. More research is needed in this area. Second, to provide a robust understanding of how mobile learning can be used in the teaching and learning of mathematics, a variety of research methodologies should be employed. Third, most of the studies report positive learning outcomes. To avoid researchers, practitioners and other stakeholders repeating failed efforts, negative outcomes also need to be reported. Fourth, from the studies reviewed, the majority of the researchers did not identify the specific mathematical concept being taught. It would be helpful for this information to be stated to inform practice. Fifth, the majority of the studies took place in elementary schools; it would appear that more research is needed at other educational levels. Sixth, with the ubiquity of mobile devices, mathematical learning can take place anywhere; however, most of the studies took place in formal educational contexts. More research could take place within informal contexts.

Future research should focus on the identified gaps in the study. It was beyond the scope of this study to investigate the validity and reliability of the research studies. Future researchers should investigate these aspects. In addition, research endeavors could also explore the best approaches for using mobile learning in mathematics.

LIMITATIONS

A systematic review of the literature is always a snapshot of the field at one particular time. Although the search of the literature was a slow in-depth process, there are articles that may have been overlooked or did not appear in this search as the title did not include a specific key term. Another limitation for this study is the way the learning outcomes were evaluated and reported. There was no consistent standard of measurement for what constituted a positive outcome. This makes it difficult to draw conclusions as to the meaning of the results. In addition, this systematic review did not report on the size of the individual studies. Finally, the researchers only reviewed studies published in English, limiting the review of all potential studies.

CONCLUSION

The findings of this systematic review provide new information for the academic field of mobile learning in mathematics. Specifically, eight new findings have emerged from these data: (1) Most of the studies on mobile learning in mathematics focus on effectiveness, followed by mobile learning design as the primary research purpose; (2) Most researchers of mobile learning in mathematics adopted case studies and experimental design as primary research methods; (3) Most studies of mobile learning in mathematics report positive outcomes; (4) Mobile phones are currently the most widely used device for mobile learning in mathematics; (5) The study of the use of mobile devices for mathematics learning is most common in elementary school settings; (6) The majority of the researchers do not identify a specific the mathematical concept being studied; (7) The majority of the studies took place in formal educational contexts; and (8) Research on mobile learning in mathematics is geographically diverse, however, the majority of the studies have been conducted in the United States.

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