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Mobile technology and mathematics: effects on students' attitudes, engagement, and achievement

Introduction

The past ten years have seen substantial change in mobile computing. Schools have started integrating mobile devices in the classroom. Mobile technology is no longer just a functional accessory: it is an anytime, anywhere device for multimedia, data gathering, data processing and more. Potential benefits of using mobile technology for learning include: encouraging anytime anywhere learning, improving social interactions, and enabling a personalized learning experience (Shuler, 2009). In addition, mobile technologies bridge pedagogically designed learning context (Cochrane, 2010) allowing learning to be situated in a real-world context. These benefits have been observed in studies that adopt the use of mobile technologies for mathematics. Studies on mobile technologies have provided various approaches to teaching mathematics: engaging learners through game-based learning on-the-go (van't Hooft et al. 2009); connecting learners through social media (Roberts and Vänskä 2011); using the mobile phone to journal math learning (Project Tomorrow, 2010); and contextualizing learning of mathematics through the use of various phone sensors (Tangney et al. 2010),

Whilst these developments are promising, hard evidence on the use of mobile technologies for mathematics is patchy and limited. For instance, in Hwang and Tsai's (2011) review of mobile learning studies from 2001-2010, only six math studies were identified while a further review 2008-2012 had only seven (Hwang and Wu, 2012), both of which were sourced from a limited number of high impact journals. Similarly, Wu et al.'s (2012) wider search of mobile learning literature from 2003 – 2010 in indexing databases identified only three. However, as the previous literature reviews were about mobile learning in general, the implications of using mobile technologies in mathematics were not identified. Crompton and Burke's (2014) review of mobile learning studies on mathematics addresses some of these but as that review is focused on trends of mobile learning research, discussion on the effects of using mobile technology has been limited. It is the purpose of this review to bring together the research findings which do exist. The aim is to synthesize these research findings and answer the question "How have mobile technologies been used for mathematics and to what effect?"

Specifically, this review aims:

1. To create a descriptive map of research on mobile technology use and mathematics
2. To evaluate student attitudes towards mobile technology
3. To synthesize forms of engagement in using mobile technologies
4. To evaluate the effectiveness of mobile-supported activities in terms of student achievement

Mobile learning as a field has changed over the years and so has its definition. Earlier definitions of mobile learning tended to focus on the device (Traxler 2005), while recent definitions "revolve around the mobility of the learner" (Pachler et al. 2010, p. 6). As this study looks at earlier mobile learning studies and more recent ones, it is reasonable that the definition of mobile learning should capture both these perspectives and so, we follow this definition:

> "*Any sort of learning that happens when the learner is not at a fixed, predetermined location, or learning that happens when the learner takes advantage of the learning opportunities offered by mobile technologies* (O'Malley et al. 2003, p.6)"

In addition, as the range of devices that covers mobile technology has evolved over the years and continues to do so, this review focuses only on a subset of mobile devices, specifically mobile phones, handheld gaming consoles, pocket digital assistants (PDA) and tablets, as these are the mobile technologies more commonly associated with mobile learning.

Methodology

The systematic review was conducted following the approach recommended by the Evidence for Policy and Practice Information and Coordinating Centre (2007). The following section outlines the procedures undertaken:

Searching and screening for studies

This review includes a search of math-related mobile learning projects and research published in the years 2003-2012. The search process is illustrated in Figure 1.

In Cluster 1, indexing databases (Directory of Open Access Journals, Education, Information Technology Library, EBSCO, Proquest, Scopus and Web of Knowledge) were used to search for relevant studies. The keywords used were mobile, learning, mathematics and its associated terms (for a full list of keywords used, refer to Appendix A). All matches retrieved were recorded as bibliographic entries. Duplicates across and within indexing databases were removed.

The abstracts were then screened using the Exclusion Criteria (see Table 1) and were coded. An external reviewer coded a sample of the abstracts independently following exclusion criteria. The inter-rater agreement was 92%. The disagreements were mostly about what constituted mobile technologies and was resolved by clarifying the definition of mobile technologies. Abstracts of studies with insufficient information were included to be processed in the next stage. Full text versions of all remaining studies were retrieved. The studies were then filtered using the Inclusion Criteria (see below).

Table 1
Exclusion and Inclusion Criteria

Exclusion criteria	Inclusion criteria
1. Non-empirical studies 2. Non- K-12 (Kindergarten-Grade 12) participants 3. Studies that used other mobile devices (e.g. laptops, calculators, GPS) 4. Mobile learning studies on a different subject 5. Non-English	1. Papers in various forms: a case study, an experimental/quasi-experimental design, a design-based research and a report of a research study 2. Studies conducted on K-12 (kindergarten through Grade12) 3. Mobile devices used were any of the following: PDA, mobile phone, tablet, iPod® touch, handheld gaming devices 4. Student participants used a mobile device as part of a math learning activity in a formal or informal learning environment

	5. Outcomes reported detailing how the mobile device affected mathematics learning, either in terms of student perceptions, student engagement, attitude towards mathematics or student achievement.

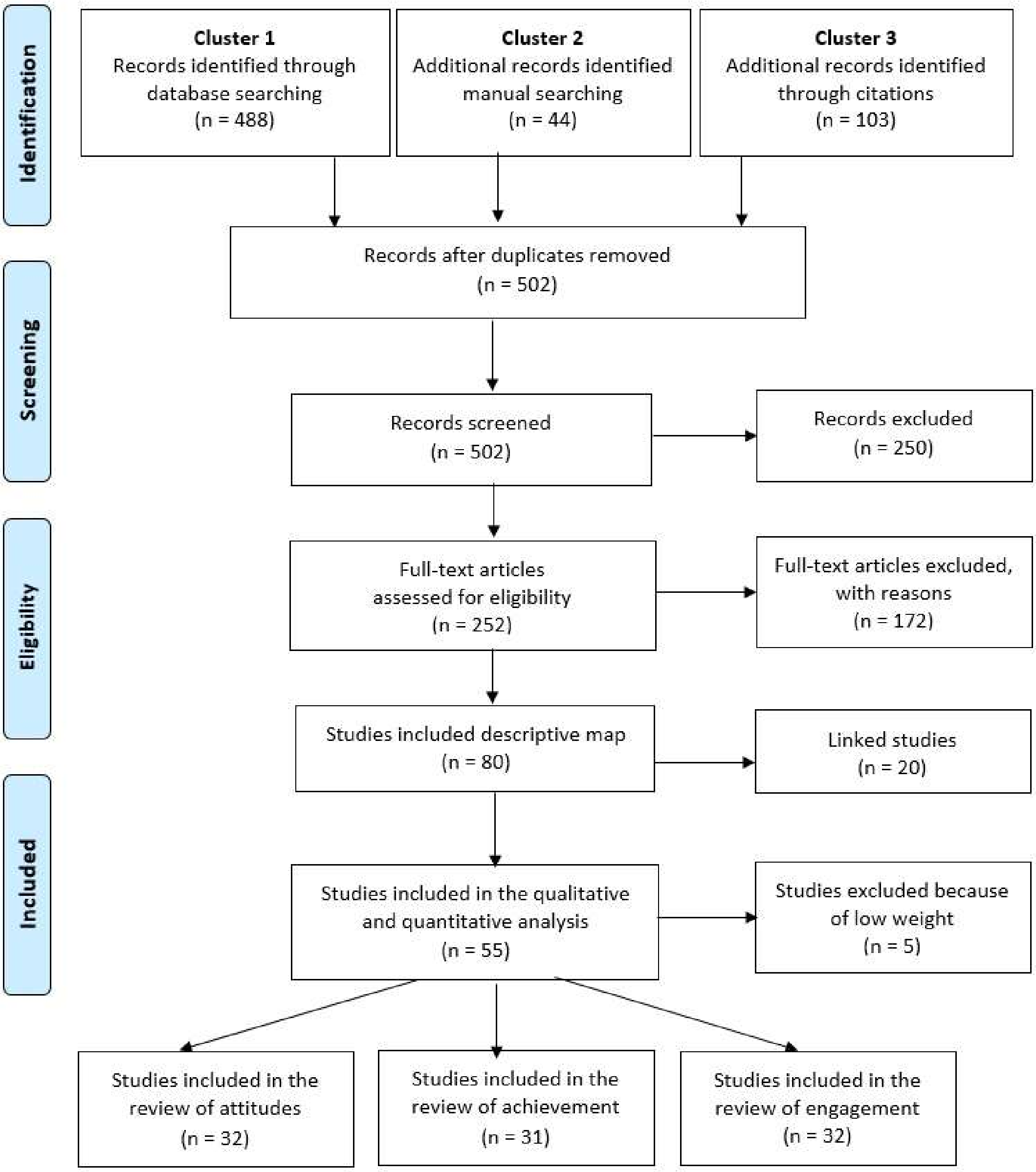

Figure 1. Modified PRISMA flow diagram

Describing and mapping of studies

The methodology and key characteristics of each of the included studies (such as country of publication, nature of activity with the mobile device and participant characteristics) were mapped into a table as shown in Appendix B. This process created a descriptive map of studies that used mobile technologies in mathematics and helped address the first objective of this systematic review.

Quality and relevance appraisal

The studies were appraised for quality and relevance by adopting Davies et al.’s (2013) rubric. The rubric judges the quality of the article in three levels: methodological quality, methodological relevance and topic relevance in a scale of 1 – 4 with 1 being inadequate and 4 being excellent. For example, research with a design that justifies all decision taken gets a rubric score of 4 for excellent methodological quality whereas a research design that contains flaws would have a rubric score of 1 for being inadequate. The score for each section in the rubric is added and the total score is translated into weights using the following conversion: 3 – 5: low; 6 to 10: medium; 11 - 12: high. Using the rubric, five studies (Kong 2008; Mahamad et al. 2008; McCabe and Tedesco 2011; Song et al. ; J. Wu and Zhang 2010) were excluded as they did not fully match the research objectives. Of the 55 studies remaining, eight studies were categorized as highly relevant (Main and O’Rourke 2011; Miller and Robertson 2010, 2011; Roberts and Vänskä 2011; Roberts and Butcher, 2009; Rosas et al. 2003; Zurita and Nussbaum 2004; Zurita et al. 2003), while the rest of the studies were categorized as either good or satisfactory and were given medium weights.

Synthesizing study findings and data analysis

The remaining studies were mapped into three learning outcomes (attitudes, engagement and achievement) to address objectives 2-4 respectively. Data were extracted from the study findings and are coded according to the three learning outcomes. In the attitudes and engagement sections, thematic analysis has been used to bring together the results of the individual studies. This involved coding data and developing themes common in the studies obtained from either the findings of the study or their primary data. For studies that discussed effect on student achievement, these were sectioned into elementary, middle school and high school levels. These studies were then synthesized by meta-analysis and vote-counting.

Before presenting the findings, it is important to note some of the limitations of this review. One limitation is the lenient inclusion criteria in terms of sample size, duration of the intervention and quality of the study. As no systematic review on math and mobile learning had been identified at the time of writing, it was felt that it would be better to include studies ranging from usability pilot tests to classroom implementations.

Results

The results are organized into four sections corresponding to the four objectives of this review: (1) descriptive map of research on mobile technology use for learning mathematics; (2) student attitudes and perception; (3) student engagement; (4) achievement.

Descriptive map of research on mobile technology use for learning mathematics

There were 80 studies found during the period of 2003-2012 that matched the inclusion criteria. Research consistently increased over the years, especially during the latter half of the decade, mostly through educational technology conferences and journals. Upon closer inspection, it appeared that some papers were referring to the same project. These papers are referred to as linked studies, reducing the total number of studies being considered to 60.

The United States heads the list of countries (n = 17) that published math and mobile learning studies, followed by Taiwan (n = 7), then Sweden (see Figure 2). While it is unsurprising that the USA tops the list, it is interesting to see how mobile learning research is not confined to developed countries but also attracts publication from developing countries. The lower number of included studies in the United Kingdom was unanticipated in comparison to the overall number of publications of mobile learning studies in the UK. This is because a number of pilot studies in the UK were school-wide adaptations of tablets and PDAs, for example the iPad® Report in Scotland (Burden et al. 2012) and so, data on mathematics are lost in the generalized report findings.

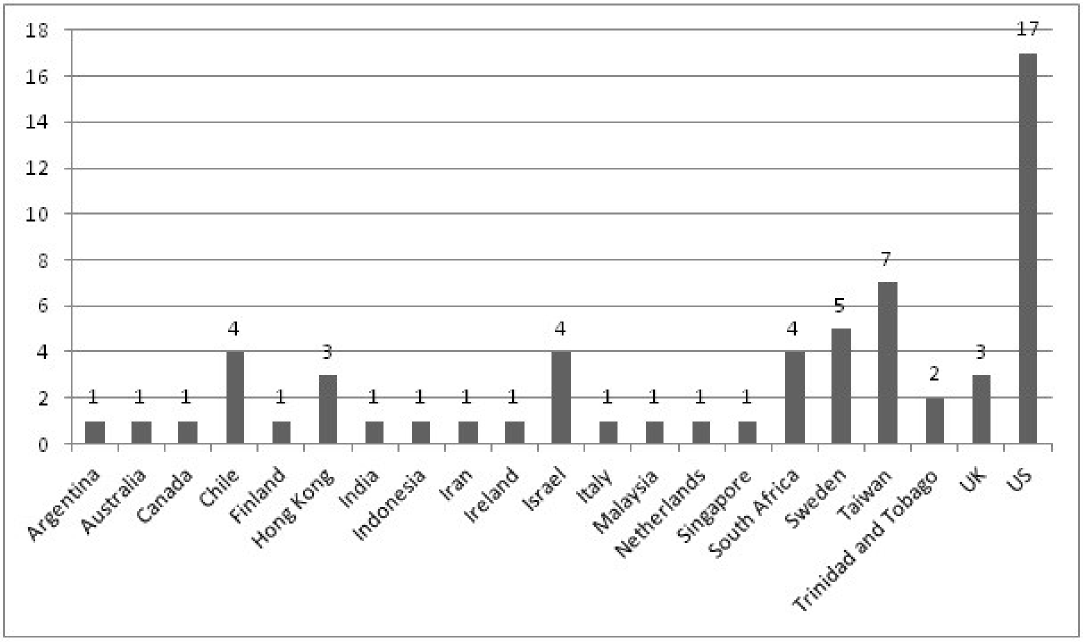

Figure 3.

The most frequently used mobile devices were mobile phones (25 studies), followed by PDAs (15 studies). More recently, the preferred mobile device was tablets. There was a spike in tablets use, from one study in 2009-2010 to 10 studies in 2011-2012. This spike is partly explained by the arrival of relatively low-cost iPads® and Android tablets. Earlier math and mobile learning studies (2003–2006) were confined to creating or re-purposing bespoke applications for mobile devices. It was only in studies published in 2009 onwards where exploitation of off-the-shelf applications began.

The design of the interventions used in the studies were greatly variable in terms of sample size and duration of the intervention (see Table 2). Most of the studies presented results as a combination of the three outcome measures and so some studies were counted more than once. For example, Main & O'Rourke (2011) investigated both attitudes and achievement; hence this study was counted once under attitudes and again under achievement. There were 32 studies that discussed student attitudes, 31 studies on achievement and 32 studies on student engagement.

Table 2

Characteristics of the Included Studies

Characteristic	Number of Studies
Level	
Elementary	30
Middle School	19
High School	11
Duration of the study	
Less than 1 week	11
Less than 4 weeks	13
Less than 10 weeks (or an academic term)	17
More than 10 weeks but less than year	8
One or more academic year	4
No data provided	7
Sample Size	
Less than 10	7
Less than 50	29
Less than 100	12
Less than 500	7
Less than 1000	3
More than 1000	1
Not specified	1
Learning Outcome Investigated	
Attitudes	32
Elementary	13
Middle School	10
High School	9
Achievement	31
Elementary	19
Middle School	6
High School	6
Engagement	32
Elementary	18
Middle School	9
High School	5

** Note that studies that are weighted low are not included in the count for learning outcomes*

The use of mobile devices for learning mathematics. Patten et al. (2006) created a framework to categorize the educational uses of mobile devices. These were administration, referential, interactive, microworld, data collection, location-aware, and collaborative. What follows is a discussion of how the studies fell into these different categories.

Administration. As Patten et al. (2006) have explained, uses of this nature have no or little pedagogy involved. In the two studies that used this function (Eliasson et al. 2010; Spikol and Eliasson 2010), both used the mobile device to push information to students as they worked in the field. However, while there was no pedagogy involved, the studies showed how mobile devices can help organize outdoor learning environments.

Referential. Referential uses of mobile devices usually involved both textual information and videos. In most examples, the content was bite-size information and accessed on demand. For example, in Engel and Green (2011) students used their mobile phones to look up information on the internet as and when the need arose in class. Another example of referential use is using tablets to access enhanced textbooks (Jaciw et al. 2012).

Interactive. Scenarios of interactive use are mainly about eliciting interactions and giving feedback in game-like activities, math manipulative and drill and practice exercises. This type of applications are either available commercial-off-the-shelf (COTS) or made bespoke for the study. Examples of math manipulative are not abundant and most studies used bespoke applications for their own study.

Drill and practice on a mobile device is similar to drill and practice on computers as both are able to provide students with immediate feedback. However, mobile drill and practice allows learners to make use of their free time to practice math (for example, on bus rides, see van‘t Hooft et al. 2009). At the same time, in countries where computers were not as common-place as mobile devices, the ability to deliver practice exercises on a mobile device allowed students to work on math exercises which would not have been available to them otherwise (Roberts & Vänskä 2011).

Microworld. Papert (1980) defined microworld as a "subset of reality or constructed reality whose structure matches that of a given cognitive mechanism so as to provide an environment where the latter can operate effectively (p. 204). Patten et al. (2006) acknowledge that there is a lack of microworld for handheld devices. In fact, of the 60 studies, none featured a microworld.

Data Collection. Mobile devices have built-in functionalities that help capture information from the environment. Most of the studies used the phone camera for gathering data, both as still pictures and videos. A typical approach is using the camera to create video blogs (Engel and Green 2011). In some studies, the cameras were paired with the phone’s sensors to measure the height of an infrastructure or the distance between two objects (Tangney et al. 2010). Other data collection activities include using Quick Response (QR) code readers to capture tagged information from the environment (Huang et al. 2012) or to have students take pictures of object that would represent a mathematics function (Baya'a and Daher 2009, 2010). An advantage of the mobile device is that it provides students an opportunity to use the outdoor environment as a medium to help visualize math concepts. Also, it allows a streamlined process of content creation and sharing as facilitated by the networking capabilities of mobile devices.

Location-aware. Mobile devices are typically equipped with built-in sensors like GPS and near field communication (NFC) receivers to allow communication between the environment, the mobile device, and the user. Examples of location-aware activities were the use of the phone's built-in GPS to measure distance between two locations (Spikol and Eliasson 2010); the use of the GPS to geo-tag information, a process of associating information with a specific place (Shih et al. 2012); or the use of the GPS to identify the user location to create a gaming environment (Wijers et al. 2010). In these examples of location-aware activities, the outdoor learning environment provided the opportunity to create connections between math and the real-world.

Collaborative Communication. Collaborative activities in mobile devices are anchored to the mobile devices' communication features like short messaging system (SMS), voice communications, Bluetooth connectivity and wireless network connectivity. The use of the mobile devices' communication tools for knowledge-sharing has been a common feature in the studies. The devices facilitated communication between students and between students and teachers both inside and outside the classroom environment.

Figure 3 shows the distribution of studies by these categorical functions. Most of the studies used the mobile devices as a combination of several functions, with some studies having at most four differing tasks, although the most frequent combination was that of interactive and collaborative.

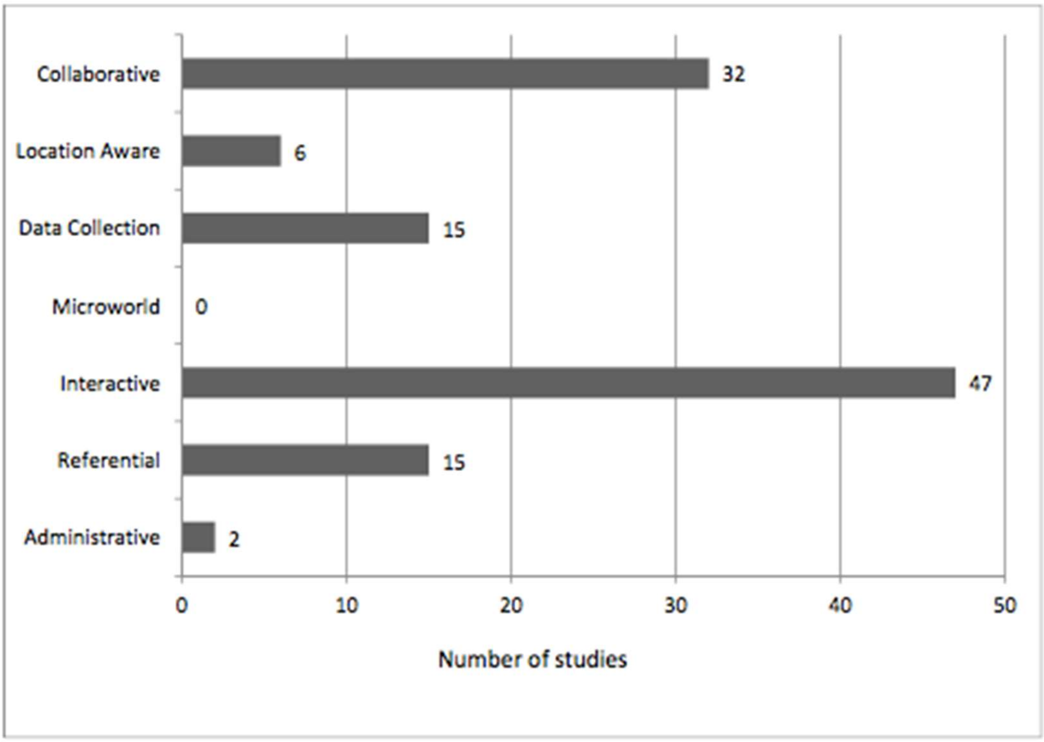

Figure 3. Distribution of studies categorized by functional use

The studies used various learning strategies to engage students in the mobile-supported learning activities. These were: direct or explicit instruction, drill and practice, formative assessment, game-based learning, visualization of math concepts, video creation or podcasting, collaborative learning, peer learning and inquiry or problem based learning. Figure 4 shows the different learning strategies used in the studies.

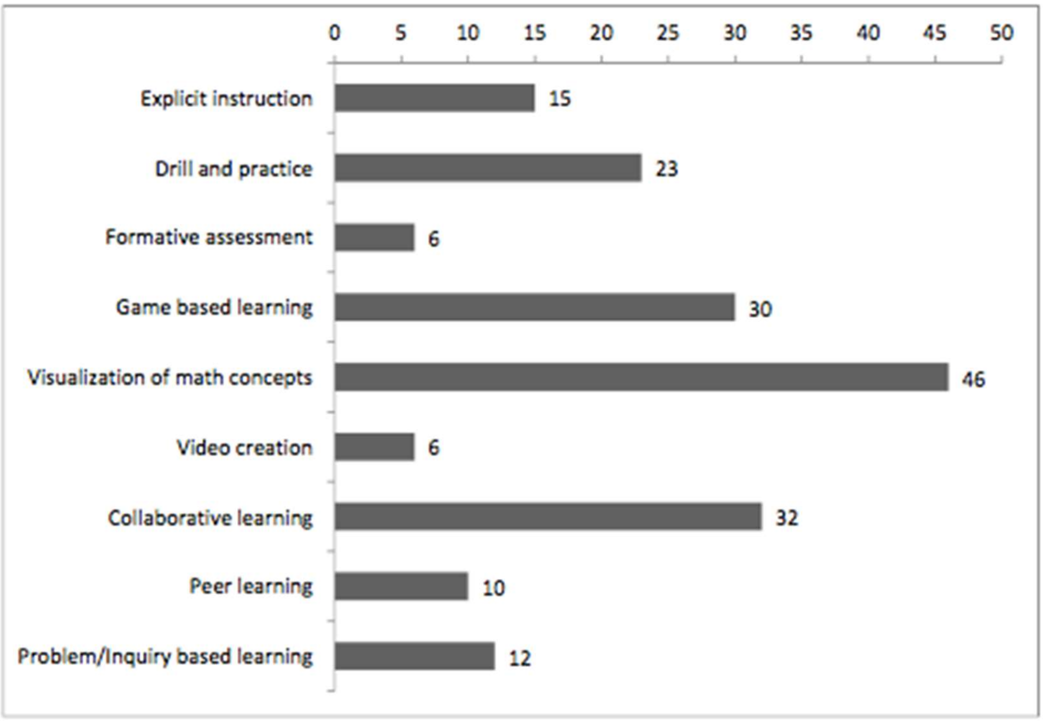

Figure 4. Distribution of studies categorized by learning strategy used

Student Attitude and Perception

The studies included in this section either focused on (a) student attitudes and perceptions towards mobile technologies or (b) student attitudes and perception towards math. The first group mostly covers the degree of acceptance of mobile technology for learning mathematics and the underlying reasons for accepting it while the second group focuses on the change in student attitudes and perceptions towards mathematics as a result of the mobile-based activity. Thus, when the students evaluate the usefulness of mobile technologies for learning math, it is assumed that they are also evaluating the activity and not the mobile device on its own. It was often difficult to identify if the study was referring to the mobile device per se or the mobile-supported activity.

Student attitudes and perceptions towards mobile technologies. There was an overall positive response towards mobile technologies for learning mathematics (except for Liu 2007). Most of the studies reported that students liked the mobile-based activity to learn math, regardless of the age group. Studies in elementary schools were most likely to report that students found the activity enjoyable and the use of the mobile device easy. The middle school and the high school groups focused more on the value of the help the mobile-based activity brought rather than the activities being enjoyable.

Novelty is a characteristic of all the studies and one that potentially affects student perceptions. Baya'a and Daher (2009, 2010) cited novelty as one of the reasons students volunteered to engage in the mobile-based activity. Several more studies reported that the technology made learning mathematics more enjoyable (Lai et al. 2012). However, this can depend on context. In Roberts and Vänskä (2011) study, students from affluent schools found the mobile-based tutorials “boring and not appealing enough, while those in poorer contexts had no such complaints (p.256).”

Game-based learning and cooperative learning activities were another common feature of studies, mentioned as a factor that engages students. Ten studies implemented a game-based learning approach and all ten had positive responses. Participants of studies that employed collaborative learning activities enjoyed the collaborative aspect of the activity as well as the help they obtained in a networked environment.

The outdoor learning environment was yet another source of student satisfaction (Baya'a and Daher 2009; 2010; Spikol and Eliasson 2010). Not only did it facilitate the visualization of math concepts, but students also found this way of learning math interesting, easier to understand and a good way to experience math - changing their ideas about math in a positive way.

Change in student attitudes and perceptions towards mathematics. Do mobile activities improve attitude towards math? Contrary evidence was found with two studies favoring mobile technology (Main and O'Rourke 2011; L. J. Wu et al. 2006) and three studies did not (Jaciw et al. 2012; Miller and Robertson 2010, 2011). Wu et al. (2006) found that students who used the mobile device improved their attitudes towards mathematics after the intervention, while Jaciw et al. (2012) found otherwise. Main and O'Rourke (2011) found that the intervention group improved their self-concept for mathematics, but there was no significant improvement in the control group. On the other hand, Miller and Robertson (2010) found no improvement in the experimental group's math self-concept scores, although there was a significant fall in math self-concept in the control group. Miller and Robertson (2011) replicated the 2010 study and used a random assignment with a bigger sample size but found no significant change in math self-concept and academic self-concept. However, there was an increase in student attitude towards school (although the effect size was very small).

Student Engagement

This section focuses on group dynamics, collaboration and student engagement with the mobile activity.

Group dynamics and collaboration. Kim et al. (2012) found that when a mobile device is shared between members of the group, the initial reaction was a competition between group members for control over the device. This competition was resolved by the person holding the device acting as the group leader. However, some frustration among group members was observed as they waited for the leader to try out the different answers. This frustration contributed to loss of interest and active involvement of some members of the group.

Goldman et al. (2004) gave each student their own PDA, but still found similar competition within group members at the start. A conflict broke out among students who were vying for control of their group's communication with the server. To foster collaboration rather than competition, a redesign of the social component of the activity was implemented with students within groups having rotating roles. This process resolved the competition but also made some students tune out when they were working in less critical roles.

Kim et al. (2012) tried various group configurations (individually, in groups of three or in groups of seven) in which a handheld gaming console could be shared. They found that students working individually solved fewer problems than those working in groups. However, a smaller group was preferable to a larger group - those in groups of three advanced more efficiently and quickly than those in groups of seven. On the other hand, Zurita and Nussbaum (2004) found in their co-located game that there was no significant difference between a group of three and a group of five. They concluded that "handhelds are tools that facilitate coordination of a greater number of members" (p. 308). Boticki et al. (2010) who implemented an activity with the same mechanics as Zurita and Nussbaum's found that in a co-located game with a much bigger group of students (*N*=40), strategies moved from decisions based on math to random strategies and the waiting time became long.

It is interesting how similar results regarding collaboration were derived from quite different intervention methodologies. Kim et al. (2012) had one device per group, while Zurita et al. (2003), Goldman et al. (2004), Zurita and Nussbaum (2004) and Boticki et al. (2010) had a one-to-one allocation. In Kim's study, collaboration was only in the social context; in the three studies that implemented a one-to-one allocation, collaboration was both in the digital context and in the social context. Boticki pointed out "that the understanding of shared goals was perhaps the most difficult for the primary school children to grasp" (p. 198). Goldman's solution was to do a "great deal of social engineering" (p. 5), whereby social engagement rules had to be established to provide all students the opportunity - not just those who were able to adjust the quickest in using the technology. The aim in pointing out the differences between these studies is not to seek the optimum number for group members, but rather to show how differences in design of the activity affects group dynamics and the importance of the social context in mobile learning environments.

Positive results were observed when using mobile devices for collaborative activities. Zurita et al. (2003) suggested the following benefits: 1) provides a communication channel between technological network and the social network; 2) mediates social interaction and 3) allows the participants to be mobile. These benefits have been observed in studies that opted for co-located game design. Roschelle et al. (2010) found that students who were using the mobile-based activity were communicating more than those who were using a desktop-based application. Similarly, Vahey et al. (2004) observed students communicated more in a game specifically designed to be collaborative, in comparison to a game with multi-player features but which could be played as a single player game.

Due to the novelty of the activity and the technology, some students acted as mediators and experts, providing help to the rest of the class. Baya'a and Daher (2010) also observed that there was a lot of peer support available in terms of technical support. The studies reported that these interactions are evident during the first few instances of using the technology, but eventually died down as students get more familiar with the activity/device.

Engagement with the mobile-supported activity. One of the gages used to measure student interest in the activity is the time students choose to spend on it. Both Main and O'Rourke (2011) and Lee et al. (2004) studies reported positive results in terms of time spent by students on mobile-based activities. Main & O'Rourke found that of the 20 minutes spent daily on using the handhelds, students on average spent 65% of the session on task, 25% on sharing and helping other students and 10% on non-class activity while the control group appeared to have spent more time on non-specific activities and less time completing the mental mathematics activities. Lee et al. found that each student answered as much as 1296 questions in the 19 days of the pilot study, which was 285% more than they could have finished using paper versions of exercises.

In the outdoor environment of Eliasson et al. (2010) study, students only used the mobile device to get the information that they needed and then shifted their focus to the learning environment. Sollervall et al. (2012) on the other hand reported that efficiency had much to do with the guided prompts the students were receiving on the mobile device as they progressed with the activity. They added that "the prompts appear to have provided a structure that was easy for the students to follow, without hampering their discussions and own initiatives directed at solving the tasks" (p. 39).

In Baya'a and Daher's (2009, 2010) studies, the mobile phone was used for data collection as well for communication while working outdoors. The phones were perceived to have facilitated a seamless and dynamic learning environment. These studies claimed that the system provided the students with a different perception of mathematics as a real-life modeling tool.

Overall, regardless of the design of the activity, there was an observed improvement in student engagement and participation. In comparative studies, students in the experimental group were observed to be more highly involved than the control group (Lan et al. 2010; Main and O'Rourke 2011). This involvement was in the form of assisting classmates and sharing information, increasing the amount of time spent engaging in the activity.

Student Achievement

Student achievement refers to student scores on various tests of math ability. These studies used either a standardized test, a test specifically aligned to the intervention, or a test incorporated in the game. There were 19 studies (2933 pooled participants) at the elementary level, six in middle school (411 pooled participants) and six in high school (≈1987 pooled participants). The total pooled number of participants was ≈5331.

Elementary studies: A meta-analysis. The elementary studies were the only ones where there was enough data given to permit the calculation of effect sizes (ES), a measure for quantifying the difference between two groups across studies. The ESs in Table 3 are Hedge's g, a correction of Cohen's d for smaller samples. In studies where two or more tests, the ES for each of these tests is computed then averaged so only one ES is reported e.g. (Kiger et al. 2012). Using Cohen's (1977) interpretation of effect sizes, there are a substantial number of studies with moderate to large effect sizes.

Single-group pre-post-test (SGPP) designs appeared to have higher ESs, with four studies having a large ES and another a moderate ES. In fact, S.C. Kong and Li (2007) and Liao et al. (2011) studies have the first and second highest ES of all studies. To avoid bias resulting from the type of research design, the ESs of SGPP designs are not included in the computation of the overall ES (as recommended by Lipsey and Wilson 1993). This left 14 studies to be included in the meta-analysis.

An overall ES of .30 using a fixed effect model resulted. However, a fixed effect model assumes that the ESs differ only because of the sampling error and that all studies share a common mean (Borenstein et al. 2009) which is not the case here. In this instance, the 14 studies being combined used different scales and methods and so a random effects model was more appropriate. Furthermore, heterogeneity yielded a Tau Squared of .09, a Q (*df*=13) of 38.45, and an I^2 of 66%, with statistical significance less than 0.01. Using the random effects model instead, this yielded a mean ES of .48, ranging from .27 to .68, with an SE of .10, which is a moderate effect size. Most of the studies reported a significant difference in mean test scores between the control group and the experimental group, except for three studies where the ES did not achieve significance (Carr 2012; Lan et al. 2010; Miller and Robertson 2011). A forest plot of the studies is shown in Figure 5.

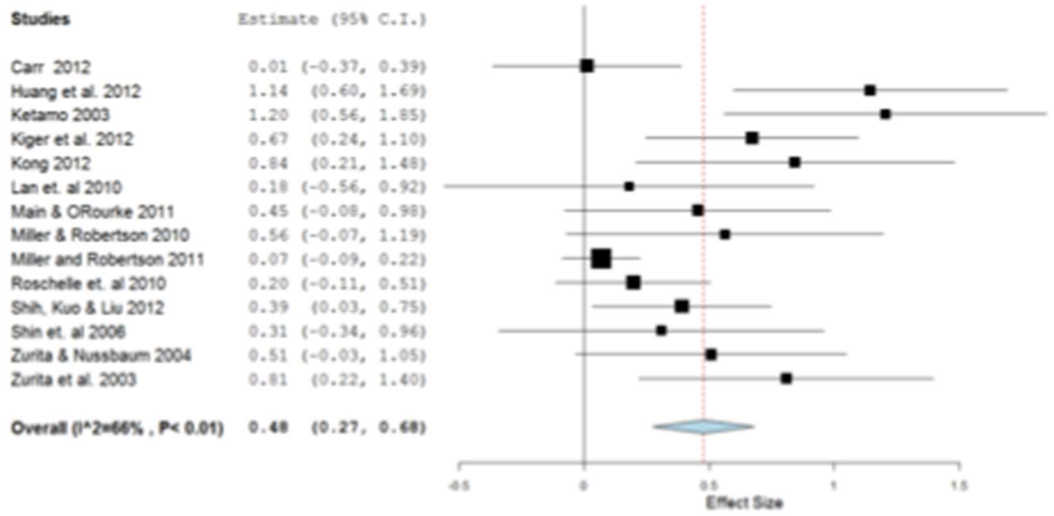

Table 3

Summary of Effect Sizes in Elementary Studies

Author/s (Year)	**Control Group**	**Pre/Post Test**	**Sample Size**	**Duration**	**Effect size Hedge's *g***
Carr (2012)	Yes	Yes	104	10 weeks	.01
Huang et al. (2012)	Yes	Post-test only	60	3 weeks	1.14
Ketamo, H (2003)	Yes	Yes	47	Not specified	1.20
Kiger et al. (2012)	Yes	Yes	87	9 weeks	.67
Kong (2012)	Yes	Yes	43		.84
Kong & Li (2007)	No	Yes	36	3 sessions	1.45
Lan et al. (2010)	Yes	Yes	28	4 weeks	.18
Liao et al. (2011)	No	Yes	9	9 weeks	1.37
Main & ORourke (2011)	Yes	Yes	59	10 weeks	.45
Miller & Robertson (2010)	Yes	Yes	71	10 weeks	.56
Miller & Robertson (2011)	Yes	Yes	634	10 weeks	.07
Rosas et al. (2003)	Yes	Yes	1274	12 weeks	Not possible to compute
Roschelle et al. (2010)	Yes	Yes	155	2.5 weeks	.20
Shin et al. (2006)	Yes	Yes	50	18 weeks	.31
Shih et al. (2012)	Yes	Yes	118	10 sessions	.39
van'tHooft et al. (2009)	No	Yes	18	6 weeks	.95
Zurita et al. (2003)	Yes	Yes	48	4 weeks	.81
Zurita& Nussbaum M. (2004)	Yes	Yes	27	4 weeks	.51
Zurita & Nussbaum (2007)	No	Yes	24	4 weeks	.65

Note: Kong et al. (2007), Liao et al. (2011), van'Hooft et al. (2009) and Zurita et al. (2007) are all SGPP and so are not included in the meta-analysis.

The effect sizes of the studies were also grouped according to characteristics like types of device used and design of the intervention. With regards to device type, PDAs had the highest ES of .62 between six studies, while handheld gaming devices had a smaller ES of .22 between four studies. Phones had no representation in the 14 studies for meta-analysis. In terms of functional use, location-aware use had a moderate ES of .74 between two studies, while collaborative use and interactive use had small ESs of .38 and .30 respectively. With regards to duration of intervention, studies of less than four weeks had a moderate ES of .55 (n = 7) in contrast to the one study that lasted 4 months which had a small ES of .31. A breakdown of the study characteristics and effect size is shown in Table 4.

Table 4

Study characteristic and random effect sizes

Study Characteristic	Random Effect Size	N	Overall number of participants
By Device Type			
Handheld gaming device	.22	4	768
Tablet	.49	5	353
PDA	.62	6	396
Phones	N/A	0	0
By Functional Use			
Administrative	N/A	0	0
Referential	N/A	0	0
Interactive	.30	14	1517
Microworld	N/A	0	0
Data Collection	N/A	0	0
Location Aware	.74	2	178
Collaborative	.38	4	291
By Learning Strategy			
Explicit instruction	.01	1	104
Drill and practice	.51	8	1065
Formative Assessment	.18	1	28
Game-based learning	.49	11	1328
Visualization of math concept	.58	9	721
Video creation/podcasting	N/A	0	0
Collaborative learning	.50	4	291
Problem-basedlearning	.58	2	695
By Duration of Intervention			
< 4 weeks	.55	7	512
4 – 12 weeks	.28	5	921
13 weeks and longer	.31	1	37

Middle school studies. Vote-counting in meta-analysis is a process comparing the number of positive studies with the number of negative studies. A vote count of studies conducted with middle school students shows a 5-1 count, with five studies reporting increases in test scores and one study reporting otherwise. Vote-counting is deemed “inappropriate” for reviews as it “ignores sample size and takes little account of study methods and study quality” (Petticrew and Roberts 2008, p.183). Nevertheless, the number of studies is small and quite diverse in implementation. Added to the fact that effect sizes were not possible to compute for most of the studies, this left vote-counting as the only possible way to measure overall effectiveness. There is thus some evidence that mobile-based activities conducted at middle school level improves student achievement.

High school studies. For the high school studies, results were divided between three studies showing positive results and three studies showing otherwise. Overall, the mobile- based activities did not cause an increase in student performance for the high school studies, but positive effects were observed based on conditions like efficiency on the part of the teacher to implement technology use.

Findings within the experimental groups. There were also differing results within the experimental groups. Findings related to within-group comparisons are as follows:

- a better improvement in post-test scores in low skill groups than in high skill groups (Ketamo 2003; Shin et al. 2012);
- the longer the time spent using the mobile device for activities, the higher the post-test scores (Kalloo and Mohan 2011; van‘t Hooft et al. 2009).
- a change in the standard deviation in the post-test scores (Lan et al. 2010; Main and O’Rourke 2011), explained as a sign of leveling of student skills.

Attitudes in relation to achievement. Attitudes and achievement are interlinked. Although the relationship between the two is not being investigated in this review, it was observed that majority of the studies which reported positive results on attitudes towards mobile technologies also obtained positive results in terms of achievement. However, there were, cases where students enjoyed the used of mobile devices and felt that the activity had helped them improve their performance in mathematics, but this did not translate into better test scores, as was the case in N. Roberts and Vänskä (2011).

Duration of the intervention. Comparing the ES with the length of the intervention (from Table 4), it can be observed that there is a slight tendency for longer interventions to have smaller ESs. An overall ES of .55 was computed for the seven studies that were less than four weeks, in comparison the overall ES of .28 of five studies that lasted between 4-12 weeks. This pattern may be explained by shorter interventions tending to maximize Hawthorne effects.

Achievement in relation to learning strategies used. Of particular note in the items discussed in Table 4 is the ES of location-aware activities (ES = .74, n = 2). Certainly this effect size is from only two studies and the other studies that employed this strategy did not present study findings in relation to achievement. Nevertheless, this seems promising and worth looking into, as this feature allows moving classroom learning into the environment and possibly facilitates connecting mathematics to real-world environments.

All studies whose functional use was that of data collection and location-awareness had favorable results in terms of achievement. Studies that used explicit instruction and formative assessment had split results, with half favoring the use of mobile devices and the other half showing that the use of these devices made no difference to student achievement. These are small numbers in comparison to the total group, which makes any further generalization impractical. Nevertheless**,** this points out how different activities are likely to elicit different results.

Summary and Conclusion

This review of the literature had the objective of identifying how studies utilized mobile devices for use in mathematics. The findings are summarized according to the four objectives set out earlier in this paper.

1. To create a descriptive map of research on mobile technology use and mathematics. *Research on the use of mobile technologies for mathematics have a wide geographical spread and has been increasing over the years.* Previous systematic reviews on mobile learning pointed out trends in the field of mobile learning and similar to the findings of these reviews, research on the use of mobile technologies for math have a wide geographical spread, with the US and Taiwan having the highest number of publications. The difference is that several countries have also emerged in the list of top sources of publication (e.g. Israel, South Africa and Sweden).

Mobile phones were the most widely used device, but this is likely to be replaced with a newer technology. Previous systematic reviews reported that the choice of mobile technology use for mobile learning studies up to 2010 are mobile phones and PDAs but may be displaced with time (Wu et al, 2010; Hwang and Wu, 2014). Whilst this study reflects the same trend so far, the additional two years difference from Wu et al.'s study has already shown a growth in the use of tablets as a preferred mobile device.

Most of the studies used the mobile devices in ways combining several functions to do a range of task. Majority of the research studies used mobile devices to replicate the interactive nature available in traditional computer-based learning activities. A difference in the design of the learning activities is that it also takes advantage of the tablets' form factor and built-in communication tools to facilitate collaborative learning environments. More recent studies have also utilized the sensors built in on the mobile device to facilitate mathematics investigation in situated learning environments but similar to Hwang and Wu's (2014) findings, studies that availed this feature are few.

The use of mobile technologies in K-12 is more common in the elementary than in high school level. Fifty-percent of the studies included in this review are with elementary participants, 32% with middle school and 18% are at the high school level. Discounting the higher education sample from Wu et al.' s (2012) and Crompton and Burke's (2014) review, this finding shows some similarities with that report.

2. To evaluate student attitudes towards technology. Student attitudes towards the use of mobile technologies in learning mathematics were mostly positive. Reasons for students liking the mobile-based math activities can be characterized into three categories: student satisfaction due to technology use, student satisfaction due to the changed pedagogy enabled by the technology, and student satisfaction with their own performance.

Due to the limited number of studies with quantitative data no conclusion can be drawn as to whether the use of mobile devices improves student attitude towards mathematics. What was apparent was that students enjoyed the mobile-based activities, but whether this enjoyment transfers to a better perception of mathematics will need further investigation.

3. To synthesize forms of engagement in using mobile technologies. The mobile form factor of the devices encouraged student-to-student interaction. During mobile learning activities, students interacted with each other more while they assisted each other, shared information and engaged in collaborative learning activities. The devices allowed students to move freely and naturally inside the classroom, whereas, in the outdoor learning environment, the mobile device facilitated remote communication between students.

4. To evaluate the effectiveness of mobile-supported activities in terms of student achievement. Positive gains were found in most of the elementary studies with only three out of 21 studies finding no significant difference between those who used the mobile devices and those who didn't. In the middle school level, the same pattern can be observed, with more studies supporting the claim that the use of mobile-based activities improves math achievement. For high school studies, this pattern of more studies reporting gains over studies reporting otherwise was not observed. There were instances of studies which reported that the use of mobile-enabled math activities had helped increased math scores, but there was no consensus on the studies conducted in high school mathematics.

Limitations

The inclusive nature of the study has led to studies with varying nature of research design and implementation, some had been small-scale studies while others had been large national projects. Smaller sample sizes over-emphasize the results be they positive or negative. For instance, one of Lai et al. (2012) findings is "70 percent of the students show more interest in reviewing math than before" (p. 285). While 70% appears to be an impressive increase, this is actually just 7 students showing more interest. This illustrates that caution had to be exercised when consolidating study findings.

Short-term implementations are more exposed to Hawthorne effects. However the decision to include both short-term and long-term studies had its merits. Small-scale short-term trials were specific in discussing the activities carried out by the students while larger scale long-term studies focused on the results rather than on the activities. The two types of study represent ends of a dimension. The short-term projects helped identify the activities that could be carried out with mobile devices as well as the engagement it elicited from the students while the long-term studies provided more information regarding improvement in student outcome.

Majority of the studies included in this review had medium weights with only 15% of the studies achieving a high score in terms of methodological quality and methodological relevance. A critical reader may find this review as a summary of mediocre studies, but this also highlights how mobile learning is still in its infancy stage. Perhaps, in the future, mobile learning studies would have a more rigorous research approach but for now the quality of the research that has been included in this review has been sufficient to draw some generalizations of how mobile technologies have been used over the past decade.

In addition to the shortcomings listed above, another limitation of this review is its failure to retrieve early studies of mobile learning. There were identified projects on math and mobile learning that weren't included because information on the project can no longer be retrieved. Examples of this are the Palm Handheld Integration Project (TIC TOC) and TARGET PAALM Grant Project, both from the once extensive list of Palm funded studies that are no longer available for retrieval after the funding company collapsed. This reflects the highly evolving nature of mobile technology and how studies can become easily outdated.

Gaps in the Literature

This study drew out the trends on the use of mobile technologies for mathematics and identified some of the effects of using mobile technologies to students' attitudes, engagement and achievement in mathematics. Through the process of finding patterns in the literature, some gaps have been identified. One gap is that interventions which aimed to use mobile devices in outdoor learning environments lacked evaluation in terms of student achievement and focused on the discussion of student engagement or student attitudes. Another gap was that most of the interventions reviewed were short and it would be interesting to investigate how mobile devices can support learning mathematics over longer periods of time. Also, most of the studies lacked the teacher's voice. While some studies have provided data from teachers, most of this has been perceptions of student improvement and not the teacher's attitudes and perception on the use of mobile technologies. Furthermore, there is a gap in terms of discussion on how mobile technologies support the learning process in mathematics. Tsai and Hwang (2012) proposed that studies should consider linking pedagogical theories to technology-based learning and this is a gap that most studies in this review has not addressed. Quite often, discussions of math and mobile learning studies have been limited to surveys, observations and maths tests at the end of the intervention but failed to address how these evidences link to the learning process.

Conclusion

One of the learning benefits of using mobile technologies is the access to information students have via different channels: teachers, peers and software applications. Teachers are the least available, peers somewhat more available, but the mobile device is available anytime. Such is an exemplification of the mobile learning tagline “anytime, anywhere learning” - where learners can use the mobile device regardless of where they are and when they need it. The positive results of mobile-based activities have shown that mobile devices are suitable alternatives to desktop computers to aid in the visualization and conceptualization of mathematical concepts. At the same time, mobile devices are being harnessed to promote a collaborative learning environment. Moreover, recent studies have explored harnessing the mobility of the mobile device to carry out mathematics investigations outside the classroom environment. While studies that were carried out in the outdoor environment lacked the formal evaluation relating to achievement, this shows the potential of mobile technologies to bridge classroom mathematics to real-world math.

In these studies, questions like “what makes mobile learning different from other technologies?” or perhaps “how important was the role of mobile devices in implementing the study?” might be asked. Earlier, the use of the mobile device in the majority of the studies had been to replace desktop computers in the classroom. Few studies explored capitalizing on the mobility features of the mobile device. It can even be argued that the positive effects observed cannot be attributed solely to the use of mobile technology, but more to the learning strategy adopted. However, it can also be argued that it was the ubiquity of the mobile device that facilitated the change just by responding to the problem of access to technology. This highlights how implementations of Bring-Your-Own-Device (BYOD) scenarios are possible sustainable options for schools - scenarios where schools do not have to provide all the technology to enrich existing activities. Nevertheless, there are also studies that engaged students in situated learning environments by harnessing the portability of the mobile device. In implementations such as these, the use of the mobile device were not just a substitute tool but rather was used to push boundaries and carry out mathematics investigations outside the classroom.

This review adds to the body of evidence that supports the use of mobile technologies for learning mathematics to help decision makers and practitioners make informed choices regarding mobile technologies. The past ten years of implementing mobile technologies for learning mathematics have made a modest difference in the classroom in terms of student achievement. Student responses and perceptions to this technology have been positive and so has been the engagement that it has elicited. In the ten year period that this review covered, the first half of the decade had more studies that focused on substituting traditional computers with mobile devices, but as the devices improved over the years, new forms of using mobile technologies have emerged, highlighting the possibility of using mobile devices to bridge classroom learning to real-world.

An update of this review is planned to be carried out in 2017 to cover studies from 2013-2016.

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