2018

Mobile Learning and Student Cognition: A Systematic Review of PK-12 Research Using Bloom's Taxonomy

Helen Crompton
Old Dominion University, crompton@odu.edu

Diane Burke
Old Dominion University, dmburke@odu.edu

Yi-Ching Lin

Original Publication Citation

Crompton, H. , Burke, D. and Lin, Y. (2018), Mobile learning and student cognition: A systematic review of PK-12 research using Bloom's Taxonomy. *British Journal of Educational Technology*, 1-18. doi:10.1111/bjet.12674

British Journal of Educational Technology *Vol 0 No 0 2018* 1–1
doi:10.1111/bjet.12674

Mobile learning and student cognition: A systematic review of PK-12 research using Bloom's Taxonomy

Helen Crompton , Diane Burke and Yi-Ching Lin

Helen Crompton is an assistant professor at Old Dominion University. Her research is in the use of mobile devices to extend and enhance learning. Diane Burke is a professor emeritus at Keuka College, Keuka Park, NY. Her research interests are the learning affordances provided by mobile learning. Yi-Ching Lin is an assistant researcher at the National Applied Research Laboratories Taiwan. Address for Correspondence: Dr Helen Crompton, 3141 Education Building, Old Dominion University VA, 23529 USA. Email: crompton@odu.edu

Abstract

The rise of mobile learning in schools during the past decade has led to promises about the power of mobile learning to extend and enhance student cognitive engagement. The purpose of this study was to examine trends to determine the cognitive level students are involved in within mobile learning activities. This systematic review involved an aggregated and configurative synthesis of PK-12 mobile learning studies from 2010 to 16 and used Bloom's Taxonomy as a theoretical framework for categorizing the cognitive level of student activities. Major new findings include that students are involved in activities at all six levels of Bloom's Taxonomy. This study shows that over 60% of researchers are developing activities that require high levels of cognitive processing, a large increase from past studies. Nonetheless, 40% are integrating mobile devices in ways that keep students working with minimal cognitive processing. In both elementary and secondary studies, there was a 40/60% split in the use of lower versus high level thinking opportunities. New findings show that mobile devices were integrated into science, mathematics, social studies, literacy, art and special education. Studies in science settings were the majority of the studies (40%), followed by literacy (24%).

Introduction

The rise of mobile learning in schools during the past decade has led to many promises about the power of mobile learning to improve and transform student learning (eg, Johnson, Adams, & Cummins, 2012; Law, Yuen, & Fox, 2011; Lindsay, 2016; Norris & Soloway, 2011, 2015). Researchers (viz., Friedel *et al.*, 2018 Mifsud, 2014) report greater pedagogical opportunities with mobile devices. However, others (viz., Cochrane & Antonczak, 2014; Frohberg, *et al.*, 2009; Rushby, 2012) claim that mobile devices are not being used in ways that take advantage of the pedagogical potential, and traditional pedagogical approaches are often used that have students only passively consuming content.

There is a need for studies that investigate how mobile learning is being utilized to engage students in higher levels of thinking (Koszalka & Ntloedibe-Kuswani, 2010). Researchers have conducted studies using mobile devices for learning. However, there is no empirical synthesis to uncover what cognitive levels students were engaged in during these mobile learning activities. The findings of this study will elucidate if mobile learning is being used to encourage higher level thinking.

Practitioner Notes

What is already known about this topic

- Mobile learning is an area of growing research interest and researchers are investigating the integration of mlearning into the curriculum and instruction of students' ages 2–18 years (PK-12).
- There is a paucity of research devoted to analyzing the cognitive processes in which students are engaged while using mobile learning.
- Past research has shown that students were typically engaged in low levels of cognition in mobile learning activities.

What this paper adds

- An up-to-date analysis of the pedagogical opportunities afforded students by mobile learning in relation to levels of cognition as measured by Bloom's Taxonomy.
- Research studies indicated that pedagogical opportunities exist at all levels of Bloom's Taxonomy, with the most frequent being at the understanding and creating levels.
- Evidence that there is an increasing trend toward the use of students working at higher levels of cognition; however, that 40% of researchers are still developing activities that have students working at the lower levels of thinking on Bloom's Taxonomy.
- Findings show that the most common subject to integrate mobile devices was science (40%) followed by literacy (24%).
- Findings show that from the subjects integrating mobile devices, science had the largest number of students working in high cognitive levels (62%) and literacy studies had the highest percentage of students working in low cognitive levels (45%).

Implications for policy and/or practice

- These data show that mobile learning can be used to engage students in higher levels of cognition. Opportunities should therefore be provided for students to work at higher levels of thinking in mobile learning contexts.
- More professional development is needed to ensure that practitioners have sufficient knowledge about how to plan and implement mlearning that affords students opportunities for higher levels of cognition.

The purpose of this research is to conduct a systematic review to examine how mobile devices have been used in studies with students ages 2–18 years (PK-12) from 2010 to 2015 to uncover if the use of mobile technologies has met the promise of rich pedagogical opportunities. Specifically, this aggregated review of empirical studies reveals if mobile learning activities have had students working as passive learners or if they applying, analyzing, evaluating and creating content using higher level cognitive processes. In this study, Bloom's taxonomy was used as a framework for analysis.

Background

The term mobile learning is defined as learning mediated by mobile devices which happens across multiple contexts, through social and content interactions (Crompton, 2013). Mobile devices can provide educational affordances to push the boundaries of traditional pedagogies (Norris & Soloway, 2015). However, unless the pedagogical opportunities allow for new ways of teaching and learning, the devices will not be used to their potential. The pedagogical choices determine the level of cognition the students are engaged in. Students should be actively involved in learning and thinking about the content to develop a deeper level of knowledge retention rather than memorizing forgettable facts (Stearns, 2017).

Previous research

Previous research on mobile learning has focused on investigating specific pedagogical opportunities afforded by mobile learning. The opportunity to collaborate has been reported by numerous researchers (Bressler & Bodzin, 2013; Burden *et al.*, 2014; Kulkarni, Shook, & Thomas, 2013). Other researchers (Hughes, 2014; Jones, Scanlon, & Clough, 2013; Magley, 2011) report the opportunity for increased ownership and learner agency. In addition, researchers (Ekanayake & Wishart, 2013; White & Martin, 2014) report the opportunity for increased authenticity with mobile learning.

Other scholars have conducted systematic reviews to examine mobile learning and pedagogy. Fu and Hwang conducted a review of the literature on mobile technology-supported collaborative learning from 2007 to 2016. These researchers used a collaborative learning framework to examine the data. This study showed aggregated data across all age groups including K-12, HE and adults. Hwang and Wu (2014) conducted a systematic review of the literature from 2008 to 2012 in selected journals to investigate subject matter content, learning location, types of devices, impacts on learning and student motivation and interest when using mobile technology-enhanced learning. Despite the multiple aspects reviewed in these studies, there was no investigation of the cognitive levels of students using mobile devices.

Extant analysis of cognitive processes has uncovered some initial findings. In an analysis of 102 mobile learning projects, Frohberg *et al.* (2009) found that the use of mobile technologies was not pedagogically ambitious and only a minority of the projects were aimed at realizing higher pedagogical goals. Frohberg *et al.* (2009) reported that mobile devices were primarily used as reinforcement tools to strengthen motivation and engagement. Most of the studies focused on lower-level knowledge and skills. Zydney and Warner (2016) reviewed the research on the use of mobile apps for science learning from 2007 to 2014. Using Bloom's Taxonomy, these researchers measured cognitive student learning outcomes associated with mobile applications. Their analysis revealed that lower-level cognitive outcomes, such as knowledge and comprehension were the most commonly measured learning outcomes. Higher-level cognitive outcomes such as analysis, synthesis and evaluation, occurred in only seven of the 32 studies.

Lindsay (2016) researched the use of mobile technology by 20 teachers in New Zealand schools. Results indicated that the most prevalent pedagogical approaches were augmenting learning with task activities and content access. More transformational pedagogical approaches were used less frequently.

These extant studies are focused specifically on research before 2009, a particular geographical region, or one subject area. Therefore, it appears that there is a paucity of research which investigates the students' cognitive levels while participating in PK-12 mobile learning activities across grade levels and subject areas (Zydney & Warner, 2016). This study uses a configurative analysis (Thomas & Harden, 2008) to further analyze the aggregated data to uncover new trends and overarching findings of how mobile learning is being used to cognitively engage students.

Bloom's taxonomy

Bloom's Taxonomy (Bloom *et al.*, 1956) is a framework that can be used to determine levels of thinking. Bloom's taxonomy has been used extensively in educational research (De Wever, Zhu, and Creed, 2009), and has more recently been used as a framework in which to investigate the learning processes involved in the use of technology (Diacopoulous, 2015; Ekren & Keskin, 2017; Hixon, 2011; Odhabi, 2007; Sylvia, 2014). For these reasons, Bloom's Taxonomy was selected as the framework for this study to determine student cognitive levels during mobile learning activities.

Bloom's taxonomy was created in 1956 to define and distinguish different levels of human cognition. This taxonomy was revised by Anderson *et al*. (2001) to change the categories titles from nouns to verbs to more clearly identify the specific cognitive processes involved in the learning. This allows for a greater characterization of each category's depth and breadth. In addition, the synthesis category changed places with evaluation and was renamed create.

In Bloom's Taxonomy (Anderson *et al*., 2001), the cognitive domains, from lower to higher order thinking skills, are: remembering, (ability to recall information such as dates, events, places, ideas, definitions, formulas and theories); understanding, (ability to grasp the meaning of the information, express it in own words and/or cite examples); applying, (ability to apply knowledge or skills to new situations, use information and knowledge to solve a problem, answer a question, or perform another task); analyzing, (ability to break down knowledge into parts and show and explain the relationships among the parts); evaluating, (ability to judge or assess the value of material and methods for a given purpose); and creating (ability to pull together parts of knowledge to form a new whole and build relationships for new situations).

To explicate the categories of Blooms' Taxonomy and reduce researcher interpretation Anderson *et al*. (2001) developed a table to be used to give further clarity to researchers, see Table 1.

This more granular explanation of the levels of thinking in Bloom's Taxonomy was used in this study.

Table 1: Anderson et al.'s (2001) further defined categories of bloom's taxonomy

Table 1. The cognitive processes dimension — categories, cognitive processes (and alternative names)

lower order thinking skills ⟶ higher order thinking skills

remember	understand	apply	analyze	evaluate	create
recognizing (identifying) recalling (retrieving)	interpreting (clarifying, paraphrasing, representing, translating) exemplifying (illustrating, instantiating) classifying (categorizing, subsuming) summarizing (abstracting, generalizing) inferring (concluding, extrapolating, interpolating, predicting) comparing (contrasting, mapping, matching) explaining (constructing models)	executing (carrying out) implementing (using)	differentiating (discriminating, distinguishing, focusing, selecting) organizing (finding coherence, integrating, outlining, parsing, structuring) attributing (deconstructing)	checking (coordinating, detecting, monitoring, testing) critiquing (judging)	generating (hypothesizing) planning (designing) producing (construct)

Purpose of this study

The purpose of this study was to conduct a configurative thematic systematic review (Thomas & Harden, 2008) to provide a current analysis of the research activities involving mobile technologies in PK-12 classrooms to determine the levels of student thinking. With this goal, the following research questions were developed to guide this study:

1. In Pk-12 mobile learning research, what level of Bloom's Taxonomy are the students engaged in when completing the learning activities?
2. In Pk-12 mobile learning research, is there a trend regarding levels of Bloom's Taxonomy for specific grade levels?
3. In Pk-12 mobile learning studies, is there a trend regarding levels of Bloom's Taxonomy for specific subject areas?

Method

A systematic review was conducted to ensure an unbiased synthesis and to present the findings in an impartial way (Hemingway & Brereton, 2009). Systematic reviews are a way to determine parameters, select primary data and aggregate to provide a robust picture (Oakley, 2012). In this study, in addition to aggregating the data, a configurative thematic synthesis (Thomas & Harden, 2008) was also conducted to uncover new trends and additional findings.

Search strategy

PRISMA principles (Liberati *et al*., 2009) were used to provide a framework for the search. The search of the literature was both electronic and manual. To ensure high quality studies were examined, Google Scholar Metrics were used to identify the top nine education technology journals. Google Scholar Metrics determines the rank of the journal based on the journals h-median and h-index metrics. From the list of nine journals, the *Journal of Internet* and *Higher Education* and the *Australasian Journal of Educational Technology* were removed as they were not focused on PK-12 learning. Also, the *Journal of Distance Education* was also removed as higher education is the most common population involved in distance education. The next two journals were included from Google Scholar to make the journal list nine journals. These journals are listed in Table 2 and include the h-median and h-index.

Table 2: The top nine education technology journals with h5 -index and h5-median

Google Scholar Rank	*Journal*	*h5-Index*	*h5-Median*
1	Computers and Education	94	137
2	British Journal of Educational Technology	53	78
3	Educational Technology and Society	49	72
4	Journal of Computer Assisted Learning	41	84
5	The International Review of Research in Open and Distance Learning	37	68
6	Educational Technology Research and Development	34	50
7	IEEE Transactions on Learning Technologies	29	44
8	International Journal of Computer-Supported Collaborative Learning	26	35
9	Language Learning and Technology	24	39

To search the journals for relevant articles, 10 search terms were used: "mlearning," "mobile learning," "tablets," "hand-held," "wireless," "iPad," "location-aware," "situated learning," "ubiquitous learning," "context-aware," "digital learning." These terms were chosen as they are terms often used in connection to mobile learning. Articles from 2010 to 2016 were included in this search. 2010 was chosen as the initial search date as this was the year that the iPad was launched to the public and revolutionized the tablet market. Prior to 2010, mobile technologies, such as mobile phones and personal data assistants, were often used. Tablets offer additional educational possibilities with the larger screen size. From these parameters, the initial search resulted in 321 articles.

Inclusion/exclusion criteria

Following the initial identification of research articles, further inclusion and exclusion criteria were then used to more accurately identify relevant articles. The researchers used the criteria in Table 1 to determine if a study was relevant to this systematic review. For a study to be included, it must meet all the inclusion and exclusion criteria (Table 3).

Two researchers independently examined the 321 articles against the inclusion and exclusion criteria. The researchers came to an inter-rater agreement for 96% for the coding. After discussing the misaligned articles, a 100% agreement was achieved. From this examination, 152 articles were removed from the study as they were not conducted in PK-12 settings. An additional 61 articles were excluded as they did not have students using mobile devices for learning or the research was not original. The remaining 101 articles met all the criteria. A total of 101 articles met all the criteria listed in Table 1 and a diagrammatic representation of the literature search and review process can be seen in Figure 1.

Coding

Once the initial aggregation was completed and 101 studies were identified for the review, the researchers conducted open coding to further explore trends in the data. Open coding is different than other coding methods typically used in primary research, as coding of systematic review data is conducted by a concomitant interpretation of participant data and author analysis to provide third-order constructs (Britten *et al.*, 2002).

Using Bloom's Taxonomy (Anderson *et al.*, 2001), the researchers analyzed and coded the cognitive processes students used when engaged in mobile learning. This helped researchers better understand if the pedagogical opportunities afforded by mobile technologies provided students the opportunity to engage in higher level thinking. The coding process was conducted by two researchers who examined the level of Bloom's taxonomy students were engaged in while using mobile devices.

Two of the researchers worked independently to code the studies using the Bloom's Taxonomy framework (Anderson *et al.*, 2001). This led to an 88% agreement. The two researchers met to

Table 3: Inclusion and exclusion criteria

Inclusion criteria	*Exclusion criteria*
Article was published in one of the top 10 education technology journals*	The mobile device is not a stationary gaming console
Article is original primary research	The mobile device is not a Netbook
Research takes place in PK-12 settings Students used mobile devices for learning	The mobile device is not a laptop

*According to Google Scholar 2016.

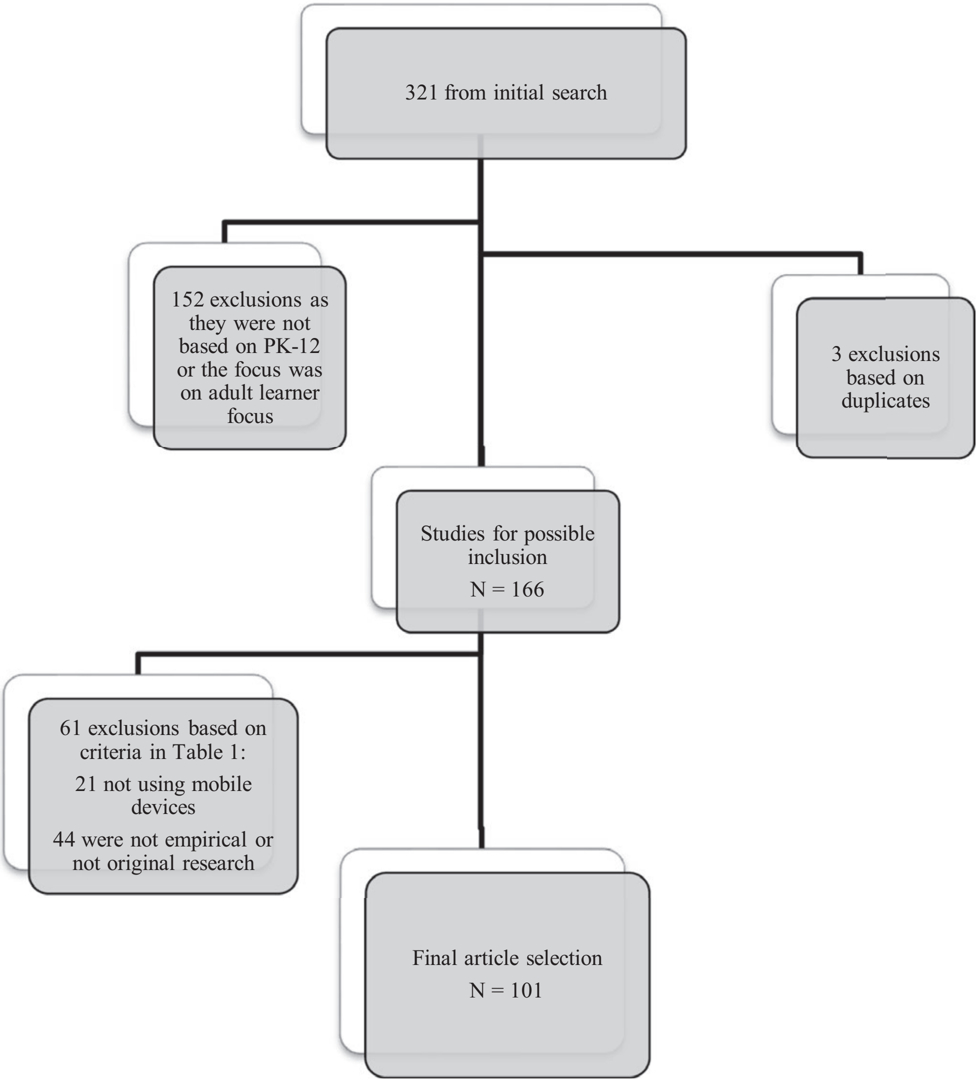


Figure 1: Analysis framework

discuss the differences and came to a 100% agreement on the placement of the studies on the taxonomy. Subject areas and academic levels (PK 2–4 years; elementary, 5–11 years; and secondary, 12–18 years) were also coded into their respective categories. During the coding process, the researchers ensured that context and original meaning of the primary data was preserved while conducting the secondary analysis (Sandelowski, Voils, Leeman, & Crandlee, 2011).

Results and discussion

The results section is organized by the three guiding questions for this systematic review.

> Question 1: In PK-12 mobile learning studies, what level of Bloom's Taxonomy are the students engaged in when completing the learning activities?

From the 101 studies, the data show that students were engaged in remembering activities, level one, 8.9% of the time. An example of Bloom's Taxonomy level one activities involved the delivery of course content to students about 25 animals distributed over five continents. Students were sent a game in which they had opportunities to recall what they had learned about the subject matter (Sandberg, Maris, & de Geus, 2011).

Understanding, level two, engaged students 32.7% of the time. A level two example had students accessing virtual 3D simulations of the solar system on tablets which allowed them to manipulate the representations to increase their understanding of planetary bodies with respect to their orbits (Schneps *et al.*, 2014). Students applied knowledge, at level three, 15.8% of the time. A level three activity included an ESL class in which students used a tablet to take pictures of objects and described them to their peers, allowing them to apply their new vocabulary (Shadiev *et al.*, 2015). Analysis, level four, engaged students 7.9% of the time. A level four example involved students playing a forensics science game on mobile devices. They had to use the tools of investigative science to analyze evidence to solve the crime (Bressler & Bodzin, 2013).

At level five, students were involved in evaluating 3% of the time. In a level five activity, students in an ecology unit took notes or pictures on a PDA and created questions about the objects they observed. This allowed them to evaluate their level of knowledge (Hung, Lin, & Hwang, 2010). Finally, at level six, students created knowledge, 31.7% of the time. An example of level six included students creating their own puppet shows and animating stories and constructing collage pictures and sharing them via social media (Fallhoon & Khoo, 2014).

Figure 2 shows the level of Bloom's Taxonomy students were engaged in when completing the learning activities.

An analysis of the number of learning activities at each level of Bloom's Taxonomy showed that 60% of the students were engaged in the higher-level thinking skills of applying, analyzing,

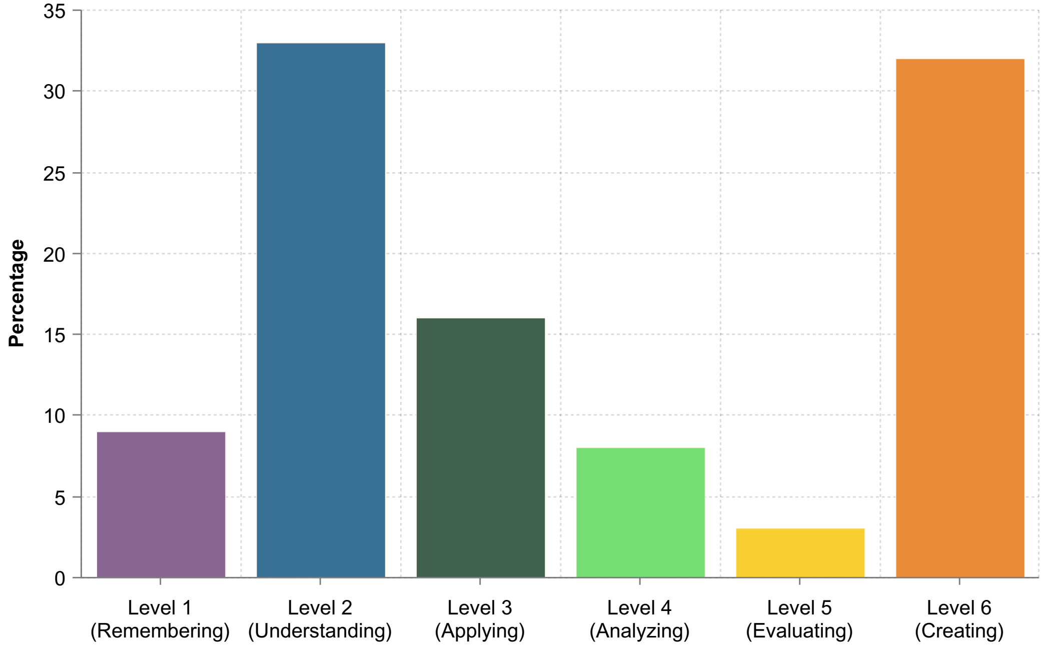


Figure 2: Percentage of activities at each level of bloom taxonomy

evaluating and creating. In addition, there is an almost equal distribution of studies in which students are engaged in either understanding or creating (approximately 33% in each category). The finding of a greater percentage of opportunities for higher-level thinking is different from previous research. Previous researchers (eg, Frohberg *et al.*, 2009) reported that the studies before 2009 had the students using lower levels of cognition. It appears that in the more recent studies analyzed in this systematic review, mobile devices are being used for activities that require higher levels of cognition. This indicates increasing mobile learning pedagogical opportunities for students to move from consumers of knowledge to producers of knowledge. However, 40% of the time, researchers involved in mobile learning are still conducting studies that use mobile learning for lower level activities on Bloom's Taxonomy.

> Question 2: In Pk-12 mobile learning research, is there a trend regarding levels of Bloom's Taxonomy for specific grade levels?

Figure 3 provides a visual representation of the data in percent at each grade level.

Pre-K (three studies)

In Pre-K settings, level two learning activities, understanding, composed 66.7% of the studies, and level six learning activities, creating, composed 33.3%. There were no other levels of learning activities represented.

Elementary (71 studies)

In 11.3% of the studies, elementary students were engaged in level one learning activities, remembering. Level two learning activities, understanding, composed 29.6% of the studies. Level three learning activities, applying, were 15.5%. Level four learning activities, analyzing, were 8.5%. Level five learning activities, evaluating, were 4.2% and level six learning activities, creating, composed 31% of the studies.

Secondary (27 studies)

In 3.7% of the studies secondary students were engaged in level one learning activities, remembering. Level two learning activities, understanding, composed 37% of the studies. Level three learning activities, applying, were 18.5%. Level four learning activities, analyzing were 7.4%. Level six learning activities, creating, were 33.3%. There were no studies in which students were engaged in level five learning activities, evaluating.

Grade level summary

An analysis of the trends of both elementary and secondary levels indicated that they mirrored the 40/60% split of lower versus higher level thinking opportunities found in the total study population. Students at both levels were being afforded the opportunity to engage in higher-level thinking in the majority of the studies. It is encouraging to note that the same opportunities are being given to students at both elementary and secondary levels. While it is very positive that students have learning opportunities at the creating level, it appears that researchers at the elementary and secondary level are also still focusing 40% of the studies at the remembering or understanding level.

Students at the PK level were engaged in understanding 67% of the time and creating 33% of the time. However, there were only 3 PK research studies which does not allow for generalizability at this academic level.

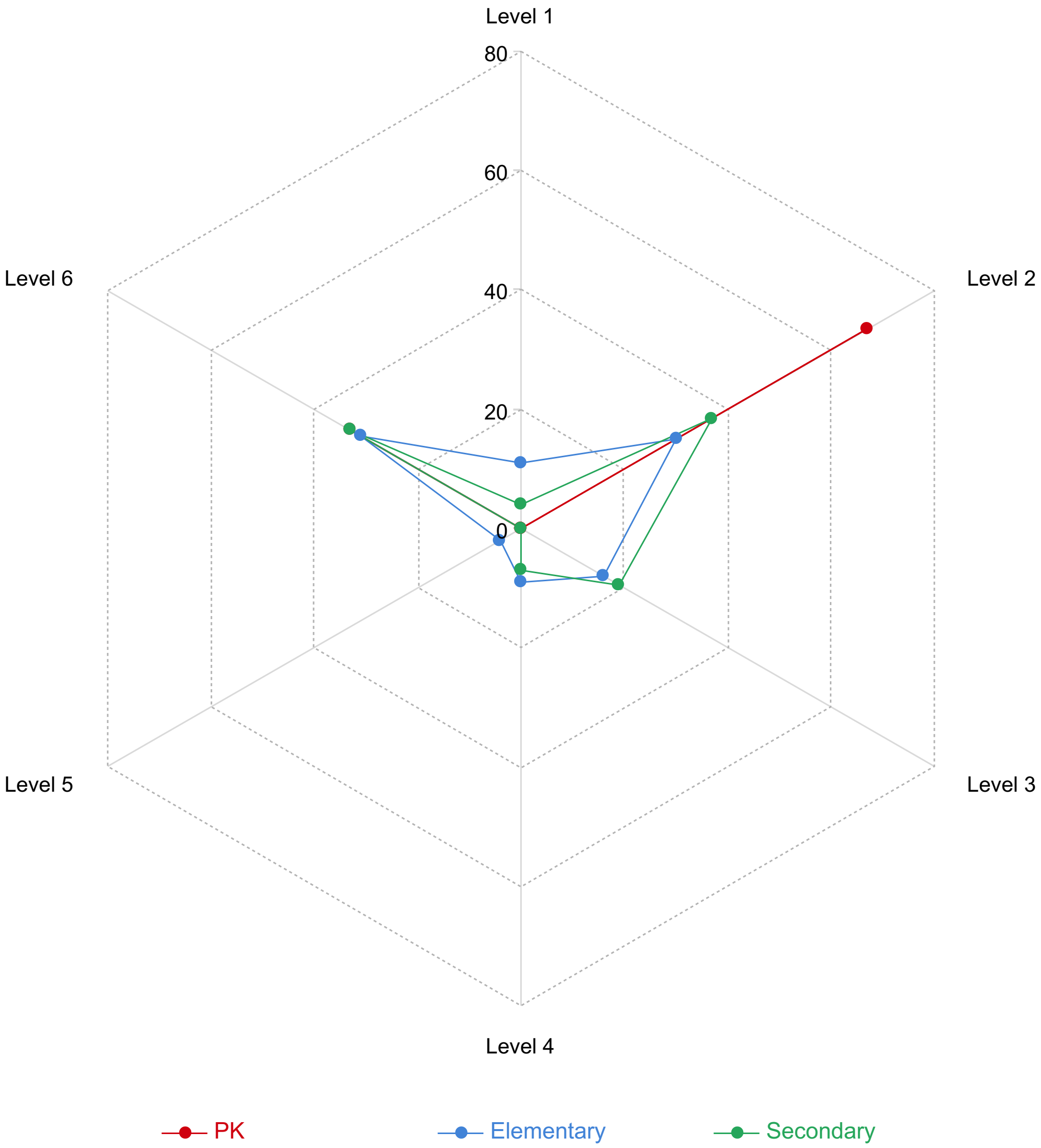
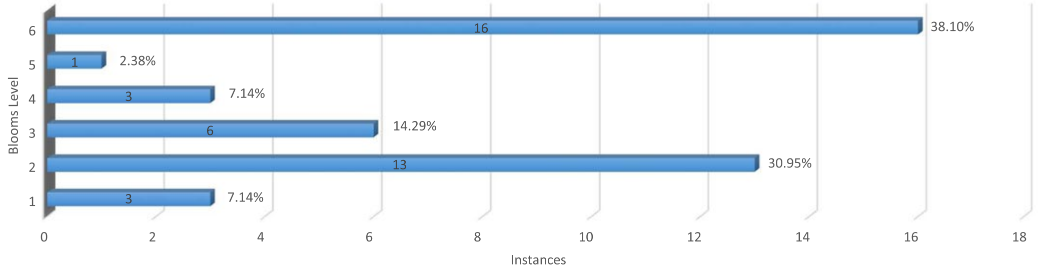


Figure 3: PK-12 mobile learning study activities categorized by academic level. Note: Level 1 = remember, 2 = understand, 3 = apply, 4 = analyze, 5 = evaluate and 6 = create. The numbers represent the number of studies

Question 3: In Pk-12 mobile learning studies, is there a trend regarding levels of Bloom's Taxonomy for specific subject areas?

These results are organized based on the number of the studies in each content area with the area with the most studies appearing first.

Table 4: Levels of student cognition in science settings



Science

Studies of the use of mobile learning in PK-12 science settings composed 41.6% of the total data set. In the science sub-set (42 studies), the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 4.

Science education should be taught by connecting learners to real-world scientific phenomenon as the students actively become involved in scientific processes, such as observing, recording and analyzing (NGSS, 2013; NRC, 2012). These type of learning experiences are facilitated by mobile learning, as tools are provided to accomplish these tasks in various geographical locations where those scientific phenomena occur (Crompton, Burke, Gregory, & Gräbe, 2016). It appears that researchers have identified this pedagogical opportunity, as research in science content areas comprised the largest number of PK-12 mobile learning studies. The science studies also provided the most robust opportunities to engage in all levels of thinking in Bloom's Taxonomy.

Literacy

Studies of the use of mobile learning in PK-12 literacy settings composed 23.8% of the total data set. In the literacy sub-set (24 studies), the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 5.

Literacy studies had a high percentage of pedagogical opportunities involving lower-level thinking (45%). This may be explained by the fact that in 20% of the literacy studies, students were using E-readers as the mobile device. E-readers are not robust tools for mobile learning, as they limit students to reading text to memorize facts or gain basic understanding. However, it is worth noting that other researchers used mobile devices in which literacy students worked at the creating level of cognition. This is evidence that the potential is there, but perhaps the type of mobile device should be reviewed for the affordances they provide. The use of devices that provide more functionality provides opportunities for activities requiring higher levels of cognition.

Table 5: Levels of student cognition in literacy settings

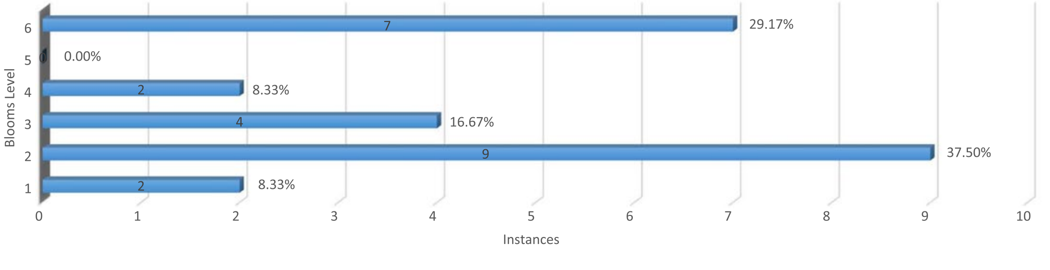
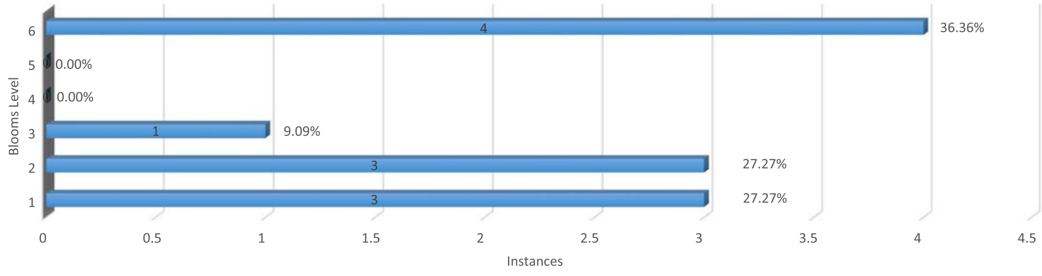


Table 6: Levels of student cognition in social studies settings



Social studies

Studies of the use of mobile learning in PK-12 social studies settings composed 10.9% of the total data set. In the social studies sub-set (11 studies) the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 6.

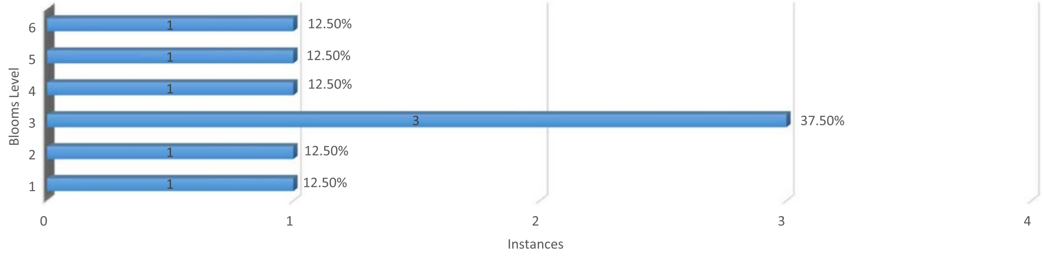
Social studies had the highest percentage of pedagogical opportunities in lower-level thinking (54%). There also were no pedagogical opportunities for analysis and evaluation. Social studies as a content area is based on many real-world phenomena as students are asked to examine various branches of human society. It appears that social studies researchers have not taken advantage of the affordances that mobile devices can provide for students to interact with real world situations. The data show that some of the researchers did use the mobile devices to have students working cognitively at the top of Blooms' Taxonomy, again providing evidence that these opportunities are available.

Mathematics

Studies of the use of mobile learning in PK-12 mathematics settings composed 7.9% of the total data set. In the mathematics sub-set (eight studies) the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 7.

The highest number of pedagogical opportunities given to students in the math research studies (37%) involved applying their knowledge, level 3. As much of mathematics instruction in PK -12 classrooms typically can involve learning how to apply the mathematical skills and concepts this is perhaps an expected outcome. However, as mobile devices do provide opportunities for students at learn in new ways, it would be prudent for future researchers and educators to explore new ways that have students using higher cognitive processes.

Table 7: Levels of student cognition in mathematics settings



Multiple subjects

Studies of the use of mobile learning in PK-12 multiple subject area settings composed 7.9% of the total data set. In the multiple subject areas sub-set (nine studies) the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 8.

Studies involving multiple subjects had the highest percentage of opportunities at level six, creating. This could be the result of multiple subject studies being inter-disciplinary in nature, allowing for cross discipline creation of ideas and artifacts.

Special education

Studies of the use of mobile learning in PK-12 special education settings composed 5% of the total data set. In the special education sub-set (five studies) the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 9.

Four of the five studies identified autistic students as the population in the research studies. The characteristics of this population of students could influence the decisions about how mobile learning was used in the research. These decisions would affect the levels of thinking that the students were engaged in.

Table 8: Levels of student cognition in multi-subject settings

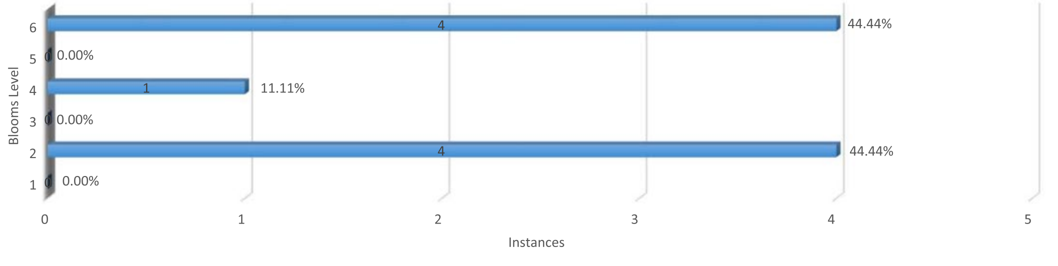


Table 9: Levels of student cognition in special education setting

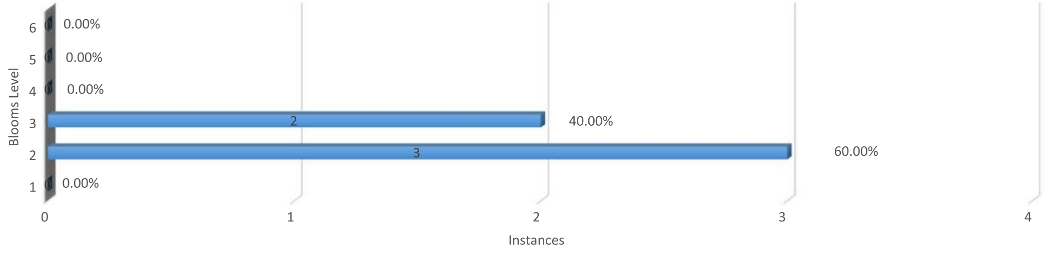
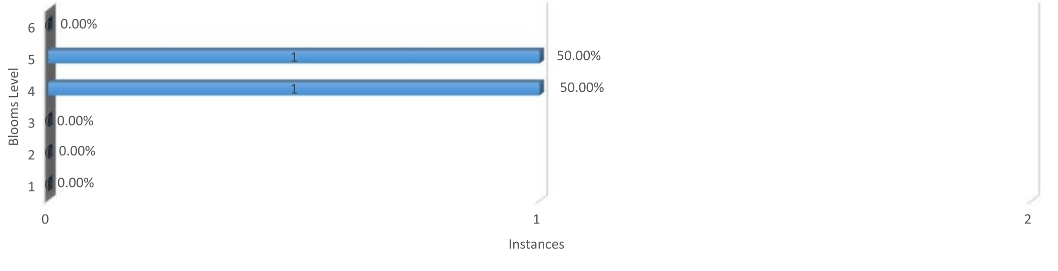


Table 10: Levels of student cognition in art settings



Art

Studies of the use of mobile learning in PK-12 art settings composed 2% of the total data set. In the art sub-set (two studies) the distribution of student engagement in the different levels of Bloom's taxonomy is indicated in Table 10.

There were only two studies in art, so it is difficult to make a generalization. However, the distribution of pedagogical opportunities was 50% in analyzing and 50% in creating. This finding was most likely due to the dominance of these two cognitive processes in this subject.

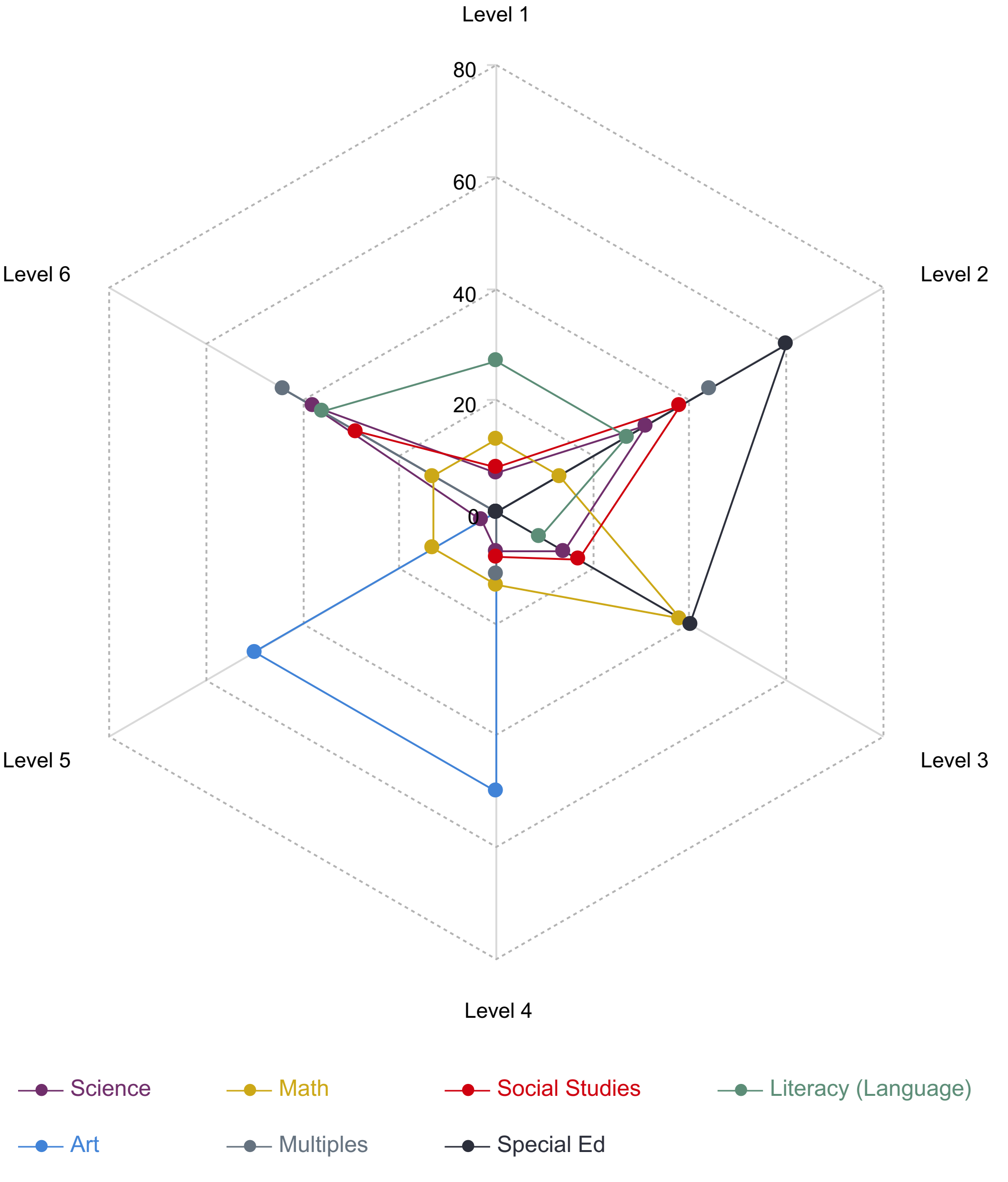


Figure 4: Percent of PK-12 mobile learning study activities categorized by subject area

Subject area summary

The results of the analysis are shown in Figure 4. Figure 4 provides a visual representation of the subjects and levels of Blooms Taxonomy for the activities in percent.

An overall analysis of the pedagogical opportunities indicated that only two subject areas provided opportunities at each level of Bloom's Taxonomy, science and mathematics. Only three content areas provided opportunities for evaluation, science, math and multiple subjects. This study provides evidence that mobile devices can and are being used to facilitate higher levels of thinking. However, they are still often used for lower levels of thinking.

Conclusions

From this systematic review new findings have emerged. The data show that PK-12 mobile learning studies have students using mobile devices for cognitive processing at all six levels of Bloom's Taxonomy. Forty percent of the activities had students working at levels one and two, remembering and understanding, and 60% were at levels three to six, applying, analyzing, evaluating and creating. These data are different from past research findings (Frohberg *et al.*, 2009; Lindsay, 2016; Zydney & Warner, 2016) that report most studies having students working at the lower levels of cognition. Academics (viz., Johnson, *et al.*, 2012; Law, *et al.*, 2011; Lindsay, 2016; Norris & Soloway, 2011, 2015) have posited the potential of mobile learning to transform teaching and learning. This discovery of the increased use of mobile learning for higher level thinking is evidence that this is possible. The research reviewed in this study provided evidence that students are using mobile learning to move beyond consuming knowledge and are using the higher cognitive skills of analysis and creation.

This shift of using mobile devices for higher level thinking occurred at all three grade levels investigated, Pre-K, elementary and secondary. These new findings show that in elementary and secondary studies, there was a mirrored 40/60% split in the use of lower versus high level thinking opportunities. In Pre-K settings only two levels of Bloom's Taxonomy were represented, level two understanding and level six creating. However, with only three studies at this level, more research is needed to better understand the use of mobile devices in this setting.

As subject areas were examined, new findings show that mobile devices were integrated into science, mathematics, social studies, literacy, art and special education. Studies in science settings were the majority of the studies (40%), followed by literacy (23.8%). For all subjects, there is evidence that mobile devices were used to have students working at high cognitive levels, with many examples at level six, creating. These findings show that mobile devices provide the affordances allowing students to work at higher levels of thinking. However, the findings also show that students are still often being asked to use the mobile devices to work at lower levels despite the evidence of the potential of these tools.

Identified gaps and future research

This study was conducted to better understand if the use of mobile devices allowed students to engage in higher level thinking. The results of this study are encouraging in that the data show research activities are connecting students with higher levels of thinking, however, there is a need for further research to expand this knowledge base. The findings of this study reveal three gaps in academic understanding. First, more research is needed in how the use of mobile technologies can provide pedagogical opportunities to promote higher levels of thinking. For example, researchers could explore the design of various activities that would connect students with the higher levels of Bloom's Taxonomy. Second, it would be prudent for researchers to identify the functions that specific mobile devices have (eg, iPad, e-Readers), and how they can be used to support learning at different levels of cognition. Research matching device functionality and levels of thinking could allow a better understanding of how to use mobile learning to promote higher level thinking. Third, while more research is needed in all curriculum areas, the findings of this research show a particular gap in mathematics, art, social studies, languages and students with special needs. In this study, science and literacy were the two subject areas which most often promoted higher level thinking with mobile learning. The academic community would benefit from future researchers investigating how to promote higher level thinking using mobile devices in other subject areas. Researchers could investigate how mobile devices were used successfully in science and literacy, and then look to see if these practices would transfer to other subject areas. Researchers could also match some of the types of activities students should be involved in for a particular subject area (eg, observing, note taking, recording) and investigate how mobile devices can support students as they engage in these tasks.

Limitations

Systematic reviews are a snapshot of the published studies during that period and with the rapid changes of technology on society, these findings may change in the near future. The inclusion criteria favored specific types of journals and other researchers may want to extend the research with broader criteria for journal selection. The journal search was a rigorous process but only reflects a study of journals published in English. This study covered various subjects and groups of students. However, some of the data sets were small and generalizations should be avoided in these instances.

Statements on open data, ethics and conflict of interest

The data are gathered from Open Access Databases that can be accessed through university subscription or from access through local libraries.

Institutional Review Board approval not needed for this systematic review.

There is no conflict of interest.

Acknowledgements

The authors would like to acknowledge the work of John-Paul Asija and Elizabeth Martin in developing visual data graphics to accurately represent the data in this study.

References

Anderson, L. W. (Ed.), Krathwohl, D. R. (Ed.), Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., & Wittrock, M. C. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of educational objectives.* Complete ed. New York: Longman.

Bloom, B., Englehart, M., Furst, E., Hill, W., & Krathwohl, D. (1956). Taxonomy of educational objectives: The classification of educational goals. *Handbook I: Cognitive domain*. New York: Longman.

Bresser, D. M., & Bodzin, A. M. (2013). A mixed methods assessment of students' flow experiences during a mobile augmented reality science game. *Journal of Computer Assisted Learning, 29*(6), 505–517.

Britten, N., Campbell, R., Pope, C., Donovan, J., Morgan, M., & Pill, R. (2002). Using meta ethnography to synthesize qualitative research: A worked example. *Journal of Health Services Research and Policy, 7*(4), 209–215.

Burden, K., Hopkins, P., Male, T., Martin, S., & Trala, C. (2012). *IPad Scotland evaluation: Faculty of Education, the University of Hull*, UK. Retrieved January 25, 2016, from https://janhylen.se/wp-content/uploads/2013/01Skottland.pdf

Cochrane, T., & Antonczak, L. (2014). Implementing a mobile social media framework for designing creative pedagogies. *Social Sciences*, *3*(3), 359–377.

Crompton, H. (2013). A historical overview of mobile learning: Toward learner-centered education. In Z. L. Berge, & L. Y. Muilenburg (Eds.), *Handbook of mobile learning* (pp. 3–14). Florence, KY: Routledge.

Crompton, H., Burke, D., Gregory, K., & Gräbe, C. (2016). The use of mobile learning in science education: A systematic review. Journal of Science Education and Technology, *25*, 149–160.

De Wever, B., Zhu, C., & Deed, C. (2009). Supporting active cognitive processing in collaborative groups: The potential of bloom's taxonomy as a labeling tool. *Internet & Higher Education*, *12*(3/4), 165–172.

Diacopoulos, M. (2015). Untangling Web 2.0: Charting Web 2.0 tools, the NCSS guidelines for effective use of technology, and bloom's taxonomy. *Social Studies*, *106*(4), 139–148.

Ekanayake, S. Y., & Wishart, J. (2013). Mobile phone images and video in science teaching and learning. *Learning, Media and Technology*, *39*(2), 229–249.

Ekren, G., & Keskin, N. (2017). Using the revised bloom taxonomy in designing learning with mobile apps. *GLOKALde*, *3*(1), 13–28.

Fallhoon, G., & Khoo, E. (2014). Exploring young students' talk in iPad-supported collaborative learning environments. *Computers & Education*, *77*, 13–28.

Friedel, H., Bos, B., Lee, K., & Smith, S. (2013). Paper presented at the Society for Information Technology & Teacher Education International Conference (SITE) 2013. New Orleans, 2013(1), 3708–3717.

Fu, Q. K., & Hwang, G. J. (2018). Trends in mobile technology-supported collaborative learning: a systematic review of journal publications from 2007 to 2016. *Computers & Education*, *119*, 129–143.

Froberg, D., Goth, C., & Schwabe, G. (2009). Mobile learning projects – A critical analysis of the state of the art. *Journal of Computer Assisted Learning*, *25*, 307–331.

Hemingway, P., & Brereton, N. (2009). In *Hayward Medical Group* (Ed.), What is a systematic review? Retrieved October 24, 2014, from https://www.medicine.ox.ac.uk/bandolier/painres/download/whatis/syst-review.pdf

Hixon, E., Buckenmeyer, J., & Zamojski, H. (2011). Bloom's taxonomy meets technology: An instructional planning tool. *Online Classroom*, 5–8.

Hughes, J. (2014). *Using mobile apps to transform teaching and learning in literacy*. In M. Searson & M. Ochoa (Eds.), Proceedings of SITE 2014–Society for Information Technology & Teacher Education international conference (pp. 21–28). Jacksonville, FL: Association for the Advancement of Computing in Education (AACE).

Hung, P., Lin, Y., & Hwang, G. (2010). Formative assessment design for pda integrated ecology observation. *Journal of Educational Technology & Society*, *13*(3), 33–42.

Hwang, G. J., & Wu, P. H. (2014). Applications, impacts and trends of mobile learning – A review of 2008–2012 publications in selected journals. *International Journal of Mobile Learning and Organisation*, *8*(2), 83–95.

Johnson, L., Adams, S., & Cummins, M. (2012). *NMC horizon report: 2012 K-12 edition*. Austin, TX: The New Media Consortium.

Jones, A. C., Scanlon, E., & Clough, G. (2013). Mobile learning: Two case studies of supporting inquiry in informal and semiformal settings. *Computers & Education*, *61*, 21–32.

Koszalka, T., & Ntoedibe-Kuswani, G. (2010). Literature on the safe and disruptive learning potential of mobile technologies, *Distance Education*, *31*(2), 139–157.

Krathwohl, D. R. (2002). A revision of bloom's taxonomy: An overview. *Theory into Practice*, *41*(4), 212–264.

Kulkarni, R., Shook, A., & Thomas, K. (2013). Encinitas union school district: Use of mobile devices research study. *Mobile Technology Center*. San Diego, CA: University of San Diego.

Lindsay, L. (2016). Transformation of teacher practice using mobile technology with one-to-one classes: M-learning pedagogical approaches. *British Journal of Educational Technology*, *47*(5), 883–892.

Law, N., Yuen, A., & Fox, R. (2011). *Educational innovations beyond technology: Nurturing leadership and establishing learning organizations*. New York: Springer.

Liberati, A., Altman, D. G., Tetzlaff, J., Mulrow, C., Gøtzsche, P. C., Ioannidis, J. P. A. ⋯ Moher, D. (2009). The PRISMA statement for reporting systematic reviews and meta-analyses of studies that evaluate health care interventions: explanation and elaboration. *PLoS Med*, *6*(7), e1000100. https://doi.org/10.1371/journal.pmed.1000100

Magley, G. (2011). Grade 8 mobile one-to-one with iPads. Millis Public Schools Evaluation Report. Retrieved from:https://www.millis.k12.ma.us/node.982.

Mifsud, L. (2014). Mobile learning and the socio-materiality of classroom practices. *Learning, Media and Technology*, *39*(1), 142–149.

NGSS Lead States. (2013). *Next generation science standards: For states, by states*. Washington, DC: National Academies Press.

Norris, C., & Soloway, E. (2015). Mobile technology in 2020: Predictions and implications for K-12 education. *Educational Technology*, *55*(1), 12–19.

Norris, C., Hossain, A., & Soloway, E. (2011). Using smartphones as essential tools for learning a call to place schools on the right side of the 21st century. *Tech Trends*, *51*(3), 18–25.

NRC: National Research Council (2012). *A framework for K-12 science education: Practices, cross cutting concepts, and core ideas*. Washington, DC: National Academies Press.

Oakley, A. (2012). Foreword. In D. Gough, S. Oliver, & J. Thomas (Eds.), *An introduction to systematic reviews* (pp. vii–x). London: SAGE.

Odhabi, H. (2007). Investigating the impact of laptops on students' learning using bloom's learning taxonomy. *British Journal of Educational Technology*, *38*(6), 1126–1131.

Rushby, N. (2012). Editorial: An agenda for mobile learning. *British Journal of Educational Technology*, *43*(3), 355–356.

Sandberg, J., Maris, M., & De Geus, K. (2011). Mobile English learning: An evidence-based study with fifth graders. *Computers & Education*, *57*(1), 1334–1347.

Sandelowski, M., Voils, C. J., Leeman, J., & Crandlee, J. L. (2011). Mapping the mixed methods-mixed research synthesis terrain. *Journal of Mixed Methods Research*, *6*(4), 317–331.

Schneps, M., Ruel, J., Sonnert, G., Dussault, M., Griffin, M., & Sadler, M. (2014). Conceptualizing astronomical scale: Virtual simulations on handheld tablet computers reverse misconceptions. *Computers & Education*, *70*, 269–280.

Shadiev, R., Hwang, W., Huang, Y., & Liu, T. (2015). The impact of supported and annotated mobile learning on achievement and cognitive load. *Educational Technology & Society*, *18*(4), 53–69.

Stearns, S. (2017). The lecture and student learning. What is the place of lecture in student learning today? *Communication Education*, *66*(2), 243–245.

Sylvia, J. IV (2014). Using bloom's taxonomy to assess social media assignments. *Journal of Interdisciplinary Studies in Education*, *3*(1), 50–60.

Thomas, J., & Harden, A. (2008). Methods for the thematic synthesis of qualitative research in systematic reviews. *BMC. Medical Research Methodology*, *8*(45), 1–10.

White, T., & Martin, L. (2014). Mathematics and mobile learning. *Tech Trends*, *58*(1), 64–70.

Zydney, J., & Warner, Z. (2016). Mobile apps for science learning: Review of research. *Computers & Education*, *94*, 1–17.