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A review of experimental mobile learning research in 2010–2016 based on the activity theory framework

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ABSTRACT

In this study, we systematically reviewed the experimental mobile learning studies published in 2010–2016. Moreover, the activity theory framework was adopted to investigate the insights and trends of mobile learning. That is, the dimensions of context, tools, control, communication, subjects and objectives were employed to analyze the studies. It was found that most experimental mobile learning studies engaged students in real-world contexts, and the activities were conducted based on the existing school curriculums. This means that researchers and school teachers noted the value of situating students in meaningful learning by helping them link what they had learned from the textbooks to real-world scenarios or daily life environments. In the meantime, the studies frequently involved the students in actively using mobile systems with communication facilities to acquire knowledge via interacting with peers, events, and specified real-world learning targets in the environment. On one hand, many researchers proposed to raise students' motivation; on the other hand, they expected to observe more of what the learners, particularly novices and low-achievement students, had done when observing their past interactions. Even so, it was found that mobile devices were considered a main way of allowing students to acquire self-learning materials rather than only mediation learning across contexts. As the current studies can be considered to contain blended rather than purely self-paced learning, there is still a large space for mobile learning progress and development.

1. Instruction

Various issues of mobile learning have attracted much attention from researchers of educational technology and school teachers in recent years. Using devices such as mobile phones, learning systems can guide students to engage in learning tasks in a real environment, and can also immediately support related learning resources in the field and implementation of a self–assessment (Huang, Yang, Chiang, & Su, 2016; Nikou & Economides, 2016; Shih, Kuo, & Liu, 2012). Compared with conventional educational technologies (e.g., computers), mobile devices enable students to access learning content and learning guidance without being limited by their real-world locations. This implies that the learning system can guide the students to make observations, explore and collect data in the real-world environments based on the learning objectives or individuals' needs (Hsu & Ching, 2013; Martin & Ertzberger, 2015). Researchers have emphasized that “action” and “contextualization” are two important features of mobile learning. The former means that learning and teaching could occur anytime and anywhere, which decreases the limitations of accessing learning resources in conventional technology-enhanced learning or traditional education. The latter means that both digital content

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and real-world learning environments are included in learning contexts to seamlessly facilitate learning.

In the past decades, mobile learning has become a frequently-discussed issue. The research methods include observation, experimentation, questionnaire surveys, and also documentary analysis. Several researchers have concentrated on analyzing the research related to mobile learning, and have revealed some research trends in this area. For instance, Frohberg, Göth, and Schwabe (2009) used the activity theory-oriented framework to analyze the mobile learning studies published from 2002 to 2007, and briefly introduced exemplary studies for each category. The research revealed that mobile phones could be an important device facilitating communication and collaboration during the learning process. Several researchers have also recognized the suitableness of using activity theory as a framework for representing the research content and dimensions of mobile learning studies (Sharples, Taylor, & Vavoula, 2007; Sung, Chang, & Liu, 2016).

According to the literature, mobile learning has been recognized as a potential approach of education. Mobile technology can extend learning activities and can be integrated with different kinds of emerging technologies such as virtual reality and robots. However, the previous documentary analysis for mobile learning using the activity theory as a framework was conducted by Frohberg et al. (2009) who reviewed the studies published prior to 2007, while no subsequent review article has been conducted based on the framework. Other review studies for mobile learning, such as Hwang and Tsai (2011), Wu, Hwang, Su, and Huang et al. (2012) and Wu et al. (2012), were not conducted following such a well-recognized framework as the activity theory. To clarify the details of the current studies related to mobile learning and to realize the preferred activities in mobile learning, there was a need to conduct a new review on recent mobile learning publications to offer up-to-date guidelines and suggestions. Therefore, in this paper, we systematically evaluated and categorized mobile learning studies published during the period 2010–2016 in academic journals to reflect the impacts of the recent advancements in mobile technologies. Moreover, the analysis framework proposed by Frohberg et al. (2009) was adopted to analyze the studies selected in this study.

2. Literature review

Activity theory, which originated from cultural-history theory, was proposed by the Russian psychologist, Vygotsky (1978). He pointed out that human beings deeply understand the things around them and acquire knowledge through their meaningful actions, such as collaborative dialogue, interaction and other social activities. Leont'ev (1978, 1981) further developed this theory into a conceptual framework, while Engeström (1987) extended the ideas of Leont'ev and Vygotsky to explain how the individual or subgroup adjusts the original old frame in response to the challenges of the whole situation changing. The framework of activity theory consists of six elements, that is, subject, object, tools, community, rules and division of labor. Subject refers to the participants involved in activities, such as students or teachers. Object refers to the reason why the activities take place. Tools represent the content or the instrument involved in the activities, such as smart phones. Community refers to the environment in which the activities are carried out, such as a classroom or science park. Rules are the strategies or teaching mode of the activities, such as student centered learning. Finally, division of labor refers to the learning mode of the activities, such as individual or collaborative learning.

Engeström (1999) regarded that the “subject” in an activity system should not be a single homogeneous substance; instead, it must be placed into the community, according to the division of labor, and must work by abiding by the rules and objectives. Moreover, the “subject” and “object” are associated with “tools,” “subject” and “community” are associated with “rules,” and “community” and “object” are associated with division of labor. This implies that the subject uses tools to interact with objects. In the same way, the community uses the division of labor to interact with objects, and uses rules to interact with subjects (Hanna & Richards, 2012).

In the view of constructivism, teachers need to provide collaborative learning environments which can improve the reflection on students' learning process or past experiences. Mobile devices might be considered as a “*portably* collaborative environment,” which cannot be provided in the traditional instruction, for scaffolding learning anytime and anywhere. Distance and time might be bridged by mobile technology which provides a feasible method to build a *dynamic and flexible method of control*.

Activity theory has been employed in various studies and applications, such as the analysis and design of human-computer interactions (Nardi, 1996), constructivist learning environments (Jonassen & Murphy, 1999), computer-supported collaborative learning (Zurita & Nussbaum, 2007), software development (Kuutti, 1996), educational serious games (Plass, Homer, & Kinzer, 2015), mobile learning (El-Hussein & Cronje, 2010; Fulantelli, Taibi, & Arrigo, 2015; Hsu & Ching, 2013), knowledge management (Liaw, Hatala, & Huang, 2010), multi-agent collaborative virtual learning environments (Hanna & Richards, 2012), personal learning environments (PLEs) (Buchem, Attwell, & Torres Kompen, 2011), and educational technology assessment (de Freitas & Oliver, 2006; Scanlon & Issroff, 2005; Tolmie & Boyle, 2000).

The framework of activity theory for mobile learning adopted in this study was developed by Frohberg et al. (2009) based on the mobile learning framework proposed by Taylor, Sharples, O'Malley, Vavoula, and Waycott (2006). It consists of six factors, namely context, tool, control, communication, subject and objective, as shown in Fig. 1).

The factor of “context” indicates the relevancy of the environment and learning issues; there are four categories in the context factor: independent, formalized, physical and socializing contexts. The classification of these four categories is dependent on the relevance of the environment to the learning context and the pedagogic ambition. The studies categorized in the independent category indicates the lowest relevance of environment for learning context and pedagogic ambition, while the socializing context represents the highest relevance of the two. Frohberg et al. (2009) concluded that research aims to apply different levels of e-learning to improve on the traditional classroom setting. It is apparent that merely using a mobile device to access learning content is less effective than situating students in a real-world context with guidance or supports from the mobile device, implying that context

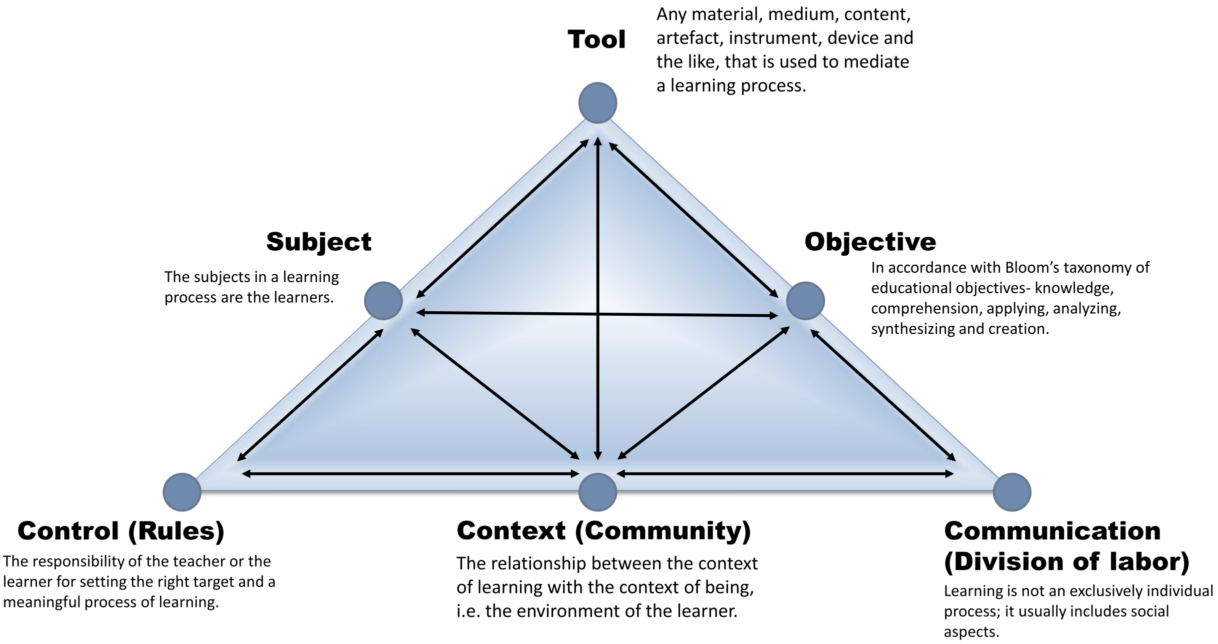


Fig. 1. The framework of activity theory for mobile learning.

awareness is an important factor of mobile learning.

The "tools" categories include "context delivery," "interaction for motivation and control," "guided reflection," "reflective data collection" and "content construction." "Context delivery" indicates that the learning tools are well-prepared materials to be delivered to learners; that is, learners read the same learning content at a low cognition level (e.g., memorizing and understanding). On the other hand, "content construction" allows learners to work actively with tools and to construct knowledge on their own. Between the two extreme categories, the three other categories are mediated by the amount of content and the integration with the real-world environment. The "interaction for motivation and control" still delivers the content, but some of it may be consumed more than just passively. "Guided reflection" delivers less content and provides more learning tasks related to the environment. Finally, "reflective data collection" engages the learners in exploring the environment. In this case, the tool plays the role of an instrument for assessment and data collection.

The factor of "control" indicates the role of teachers and learners in the mobile learning activities. This category includes "full teacher control," "mainly teacher control," "scaffolding," "mainly learner control," and "full learner control." The optimal level of control may be sufficient scaffolding and dynamic challenge for learners rather than full teacher or learner control. As such, it is important that the learners do not always passively reproduce the information provided by their teacher, but instead employ the acquired knowledge for problem solving, and actively construct knowledge. Frohberg and Schenk (2008) indicated that the control factor was likely to be ignored in conducting mobile learning in a physical context, and hence it is important to take this factor into account in designing mobile learning activities.

The "communication" factor indicates the social setting in mobile learning activities; there are five categories in this factor: "isolated learners," "loose couples," "tight couples," "communication within groups," and "cooperation." From the perspective of collaboration learning theory, learning usually includes social interaction and communication with other persons. Communication and interaction trigger deeper knowledge by engaging learners in making reflections and improvements. Mobile technology has the advantage of improving that interaction in learning scenarios by providing various communication facilities.

The "subject" factor in the activity theory for mobile learning consists of five categories, classified according to the level of their previous learning knowledge; that is, novices, less previous knowledge, good previous knowledge, more previous knowledge, and expert. The same categories have been adopted by several studies for document analysis (Hwang & Tsai, 2011; Sung et al., 2016). Meanwhile, the "objective" factor indicates the activities level based on the well-known taxonomy of educational objectives proposed by Bloom, Engelhart, Furst, Hill, and Krathwohl (1956) from lower levels to higher levels of cognition; that is, know, comprehend, apply, analyze, synthesize and evaluate. The taxonomy has been used by previous studies of educational technologies (Anderson & Krathwohl, 2001; Hwang, Chen, & Huang, 2016). There are, however, only very few studies related to a higher level of cognition, as indicated by Frohberg et al. (2009).

To sum up, the activity theory for mobile learning has been shown to be an analysis framework for completely categorizing the learning mode with mobile devices. Therefore, in this study, the mobile learning research with the experimental design was collected and analyzed based on this framework.

3. Method and search strategy

3.1. Data source

This study aimed to examine mobile learning studies according to the activity theory. The scientific method employed in this study was a narrative review, which systematically reviewed the publications from the well-recognized electronic database, SCOPUS. To ensure the quality of the reviewed studies, several highly recognized journals in the fields of educational technology or digital learning were selected, namely Educational Technology and Society, Computers and Education, Interactive Learning Environments, Computers in Human Behavior, IEEE Transactions on Learning Technologies, Computer Assisted Language Learning, the British Journal of Educational Technology, the Australasian Journal of Educational Technology, the Journal of Computer Assisted Learning, the International Journal of Higher Education, and Educational Technology Research and Development. The keywords used to search for research papers were "m-Learning," "mobile learning," "seamless learning," and "context-aware ubiquitous learning," which were defined by Hwang, Tsai, and Yang (2008). Mobile learning refers to the learning approach using mobile devices and wireless communication, while context-aware ubiquitous learning refers to the learning approaches using mobile, wireless communication and sensing technologies. Seamless learning refers to the notation that learning is not limited by location or time. After searching through those keywords, a total of 345 papers were identified.

The main focus of this study was experimental studies including true experimental and quasi-experimental design studies. In other words, pre-experimental design, non-experimental design, analytical research and those studies which only reported qualitative results were excluded from this study. Finally, 63 papers (from 2010 to 2016) were selected and evaluated according to the activity theory of mobile learning framework.

3.2. Analysis framework

By referring to the activity theory framework, six factors were adopted for analyzing the 63 papers, namely: context, tools, control, communication, subject, and objective, as shown in Table 1.

3.3. Coding and analysis

The coding was processed manually by two experienced researchers who had conducted mobile learning studies for years based on the aforementioned analysis framework. For those consistent coding items, a third researcher joined the discussion until an agreement was reached.

4. Results and discussion

4.1. Context

Context refers to the relationship between the environment and the learning tasks (Sharples et al., 2007). It contains four items, that is, the independent, formalized, physical, and socializing contexts (Frohberg et al., 2009).

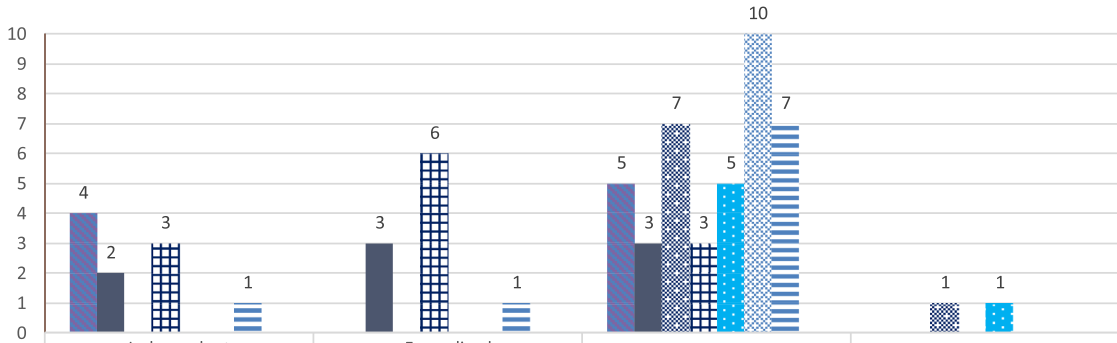
According to Fig. 2, it was found that nine studies adopted independent contexts, seven adopted formalized contexts, 40 papers reported the provision of physical contexts, and five studies provided socializing contexts. This implies that a large portion of the experimental mobile learning research provided learning tasks and materials related to the real-world locations in which the students were situated.

4.1.1. Independent context

"Independent context" refers to the fact that the environment in which the learners are situated is not relevant to their current

Table 1
The analysis framework for mobile learning research.

Section Factor	Scale				
	1	2	3	4	5
Context	Independent context	Formalized context	×	Physical context	Socializing context
Tools	Content delivery	Interaction for motivation and control	Reflective interaction	Reflective data collection	Context construction
Control	Full teacher control	Mainly teacher control	Scaffolding	Mainly learner control	Full learner control
Communication	Isolated learners	Loose couples	Tight couples	Communication within group	Cooperation
Subject	Novice	Little previous knowledge	Good previous knowledge	Much previous knowledge	Expert
Object(ive)	Know	Comprehend	Apply	Analyze	Synthesize and evaluate



	Independent context	Formalized context	Physical context	Socializing context
in 2016	4	0	5	0
in 2015	2	3	3	0
in 2014	0	0	7	1
in 2013	3	6	3	0
in 2012	0	0	5	1
in 2011	0	0	10	0
in 2010	1	1	7	0
in 2010-2016	10	10	40	2

Fig. 2. Classification of the mobile learning studies by the "context" factor.

learning tasks (Frohberg et al., 2009). Previous studies related to independent context usually focused on providing a personalized learning approach to improve students' learning performance (Oberg & Daniels, 2013; Wang, 2016). For instance, Hwang et al. (2016) developed a personalized learning diagnostic approach to help students practice and acquire specific skills through learning, while Hsu and Ching (2013) developed a mobile learning system with an English reading recommendation mechanism by taking individual students' knowledge levels and preferences into account. The mobile learning context related to the independent context revealed that the learning approach providing students with personalized learning could enhance students' learning motivation and encourage their continued efforts (Hayati, Jalilifar, & Mashhadi, 2013; Garcia-Cabot, de-Marcos, & Garcia-Lopez, 2015; Nikou & Economides, 2016).

4.1.2. Formalized context

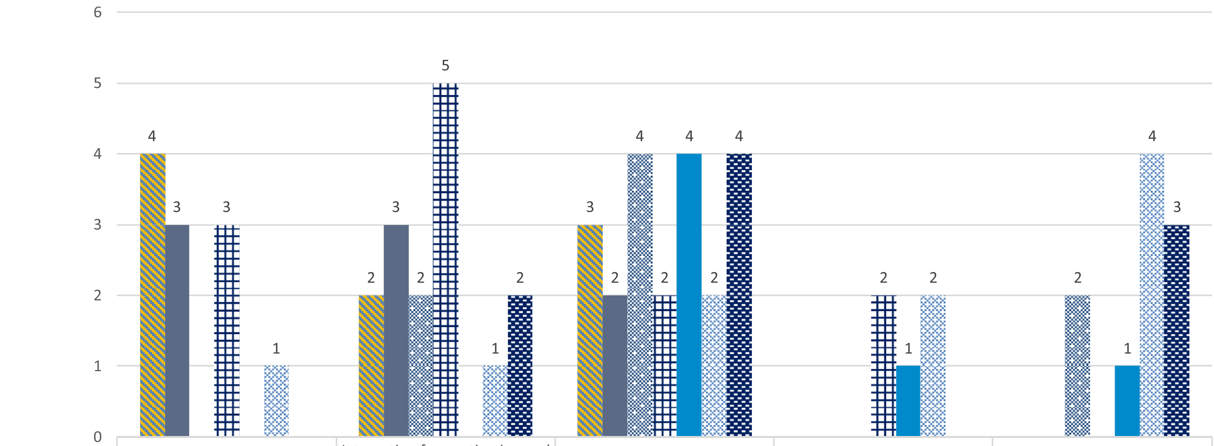
"Formalized context" refers to the mobile learning approaches supporting the classroom or in-class activities. The mobile technology in such studies plays the role of facilitating students' cognitive or corporal activation (Frohberg et al., 2009). In our analysis, 10 studies were found in which mobile learning approaches took place in a classroom. For instance, Yang, Hwang, Hung, and Tseng (2013) proposed a fill-in-the-blank concept mapping approach for helping children learn science concepts from e-books using mobile devices, while Furió, Juan, Seguí, and Vivó (2015) developed an augmented reality (AR) gaming approach to facilitate students' learning effectiveness and satisfaction with their class activities. According to the studies, it was found that a formalized learning context can support group interaction in class and encourage students to acquire and apply more learning knowledge through learning (Ahmed & Parsons, 2013; Yang, Li, & Lu, 2015).

4.1.3. Physical context

"Physical context" indicates the learning issues related to authentic places (Frohberg et al., 2009). Situating students in authentic learning environments has been emphasized by scholars for realizing meaningful learning (Hsu, Chiou, Tseng, & Hwang, 2016; Huang & Chiu, 2015). Shadiev, Hwang, Huang, and Liu (2015) have further explained that the advantage of "physical context" could help students recall their knowledge and build stronger connections between the learning content and the targeted objects, and hence have better learning outcomes (Hwang, Chen, Shadiev, Huang, & Chen, 2014; Martin & Ertzberger, 2015), lower cognitive load (Hsu et al., 2016; Sung, Hwang, Liu, & Chiu, 2014), higher learning intention (Chen & Huang, 2012), and deeper learning tendency (such as reflection, group composition and interaction) (Hsieh, Jang, Hwang, & Chen, 2011; Huang & Wu, 2011). For instance, Chang, Tseng, and Tseng (2011) demonstrated the positive impacts of location-based mobile learning on students' English listening comprehension as well as their learning perceptions. Hwang, Wu, Zhuang, and Huang (2013) reported the effectiveness of an inquiry-based mobile learning approach for improving students' learning achievement and deducing their cognitive load.

4.1.4. Socializing context

"Socializing context" refers to the activities that engage students in sharing knowledge, experiences, feelings and opinions. In the current analysis, only two studies were identified which involved online asynchronous discussions via social network facilities (Huang, Liao, Huang, & Chen, 2014) or collaborative learning tasks (Lan, Tsai, Yang, & Hung, 2012).



	Content delivery	Interaction for motivation and control	guided reflection	Reflective data collection	Content construction
in 2016	4	2	3	0	0
in 2015	3	3	2	0	0
in 2014	0	2	4	0	2
in 2013	3	5	2	2	0
in 2012	0	0	4	1	1
in 2011	1	1	2	2	4
in 2010	0	2	4	0	3
in 2010-2016	11	15	21	5	10

Fig. 3. Classification of the mobile learning studies by the "tools" factor.

4.2. Tools

Tools could be any software, medium, artifact, instrument, or device used during the learning process. Frohberg's classification of tools involves five purposes: "content delivery," "interaction for motivation and control," "guided reflection," "reflective data collection" and "content construction" (Frohberg et al., 2009). As shown in Fig. 3, the number of those mobile learning studies that used mobile devices as a tool for those five purposes were 11, 15, 21, 5 and 10, respectively. It is interesting to see that the "interaction for motivation and control" is not the only role of mobile learning systems; more importantly, the "guided reflection" numbered the highest. This implies that providing students with opportunities to reflect during their learning activities is important. On the other hand, motivation has been a very critical consideration of mobile learning design, and using mobile devices to guide students' high-level-thinking learning activities is likely to be a trend of mobile learning in the future.

4.2.1. Content delivery

In the category of "content delivery," the learner is only consuming content passively, and gains some lower level, such as factual or applied, knowledge (Frohberg et al., 2009). From the aspect of Behaviorism, learning occurs when a stimulus and the corresponding response are linked using a conditional relationship (Elfeky & Masadeh, 2016, p. p20). In the "content delivery" mobile learning activities, students are provided with learning materials via mobile devices (i.e., the stimuli), and the corresponding learning tasks, assessments, and survey from the student are the responses (Elfeky & Masadeh, 2016, p. p20). An example of "content delivery" is the study of Wu (2015), who developed a smartphone application presenting 1274 English words; another example is that developed by Chang, Chen, et al. (2011) and Chang, Tseng, et al. (2011) who provided English learning materials to students via mobile devices and investigated the impacts of the approach on students' English listening comprehension and learning perceptions.

4.2.2. Interaction for motivation and control

The "interaction for motivation and control" indicates that, in addition to delivering content, the factor of interaction is taken into account for providing a learning approach to arouse motivation. This approach can provide some feedback or records for learners as well as teachers, such as the personalized recommendation-based mobile language learning approaches (Hsu et al., 2013), interactive and real-time learning support systems (Hsu et al., 2016), higher interactive contextual mobile learning in the field (Hou et al., 2014), or interactive assessment and feedback approaches using mobile technologies (Huang & Chiu, 2015; Nikou & Economides, 2016). For example, Furió et al. (2015) developed an AR-based mobile learning approach that allowed students to have multiple interaction forms (e.g., touch-screen interaction and accelerometer) and found that the learning approach promoted the students' learning motivation.

4.2.3. Guided reflection

In the category of "Guided reflection," the main role of the learning system is to have learners reflected on the environment rather than delivering content (Frohberg et al., 2009). For example, Hung, Yang, Fang, Hwang, and Chen (2014) adopted a video-based prompt approach providing timely and personalized guidance to improve students' reflection levels in a mobile learning activity. Wu, Hwang, and Tsai (2013) proposed an expert system-based approach to providing interactive guidance for enhancing students' higher level thinking abilities. Wu et al (2012) developed a mastery mobile learning system that engaged students in practice, assessment and reflections in a nursing course.

4.2.4. *Reflective data collection*

In this category, learners are asked to explore an environment via collecting data, interpreting the data, and making reflections accordingly. The aim of this category of mobile learning is to provide learners with the opportunities to understand the observed phenomena via their own efforts to explore the environment (Frohberg et al., 2009). For instance, Hung, Hwang, et al. (2014) and Hung, Yang, et al. (2014) developed a problem-based mobile learning system to help the students collect the required data in field observation activities to improve their question-raising performance. Hung, Hwang, Su, and Lin (2012) developed a concept map integrated mobile learning approach to help students organize what they observed in the field and the content learned from the textbook. Chang, Chen, and Hsu (2011) reported an integrated WebQuest and mobile learning strategy, which engaged students in a science inquiry field trip for learning and experiencing resource recycling and classification.

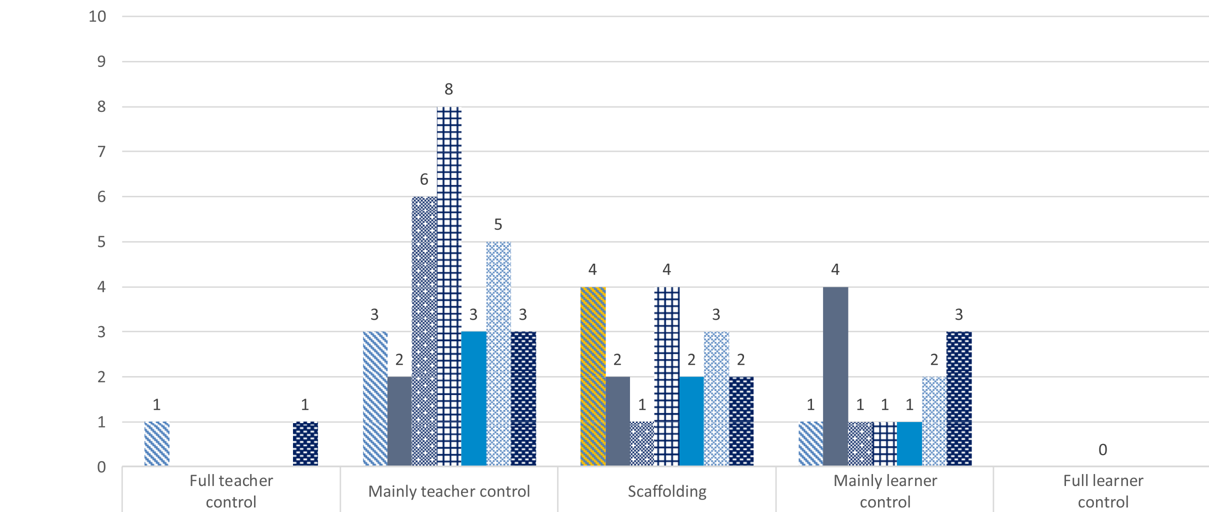
4.2.5. *Content construction*

For the highest level of tools, "Content construction" indicates that the learners work actively with the tools and construct knowledge or learning content on their own (Frohberg et al., 2009), as indicated by Brown, Collins, and Duguid (1989) who stated that learning is a form of social participation for constructing knowledge to solve problems rather than only a process of acquiring knowledge. The social communication facilitated by mobile devices can serve as such a "content construction" tool (Elfeky & Masadeh, 2016, p. p20). For instance, in the mobile learning activity designed by Sung et al. (2014), no learning content was provided during the learning process; rather, the learners were guided to produce their own content.

4.3. *Control*

Control refers to the duty of teachers or learners to determine the learning targets, tasks and the effective process of learning (Frohberg et al., 2009). In an m-learning environment, learners are engaged in real-world contexts using mobile devices with access to digital systems for supplemental resources, assessment, guidance or tasks, which could be prepared by the teacher or generated by themselves (Fotouhi-Ghazvini, Earnshaw, Moeini, Robison, & Excell, 2011).

Fig. 4 shows the analysis results of the five categories of control. Most of the studies were mainly controlled by the teachers (30 papers), and the following category was "scaffolding" (18 papers). In the past, full teacher control was considered effective for



	Full teacher control	Mainly teacher control	Scaffolding	Mainly learner control	Full learner control
in 2016	1	3	4	1	0
in 2015	0	2	2	4	0
in 2014	0	6	1	1	0
in 2013	0	8	4	1	0
in 2012	0	3	2	1	0
in 2011	0	5	3	2	0
in 2010	1	3	2	3	0
in 2010-2016	2	30	18	13	0

Fig. 4. Classification of the mobile learning studies by the "control" factor.

delivering learning content; however, students would become passive learners which would have negative impacts on their motives. Due to the rapid developments in educational technology, students now have more opportunities to explore in real contexts; however, their learning outcomes could be disappointing unless they have sufficient pre-knowledge or they are experts with good self-regulated learning ability. In other words, providing personalized m-learning guidance to individual students, especially novices or those learners with little (basic) previous knowledge, during the blended context is necessary. That is, teachers have good reason to control the learning process to avoid students' disorientation, for example, when they are not able to find the correct learning targets in the field.

4.3.1. Full teacher control

In "full teacher control," teachers provide clear guidance and learning paths for learners to gain knowledge. That is, the learners have no need to take responsibility for their own learning; they may not know why they are doing what they are doing or how to apply it on their own (Frohberg et al., 2009). Only two studies were categorized as "full teacher control" in this analysis; that is, the existing studies generally emphasize a learner-centered design based on the socio-cultural and constructivist theories.

4.3.2. Mainly teacher control

The category of "mainly teacher control" means not fully explorative learning. That is, the learning design does not intend to engage students in free exploration in the learning environment. This implies that the students do not have the opportunity to make free observations and construct knowledge; instead, they consume factual knowledge from the learning system in order to complete the quiz-based learning tasks or make observations following the path predetermined by the teacher (Frohberg et al., 2009). For instance, in the study of Hou et al. (2014), students conducted observations in physical exhibits and information searching at home following the guidance of the mobile learning system. Yang, Tseng, Liao, and Liang (2013) proposed a context-based dialogue approach for situating students in an authentic learning environment to seek appropriate resources for gaining knowledge based on their needs.

4.3.3. Scaffold control

"Scaffold control" refers to the learning contexts in which learners are required to perform their activities following a conceptual framework to gain experience and knowledge. For example, Hsu et al. (2016) employed a learning support system for guiding students to learn based on the predetermined learning path to maximize their learning outcomes. Wu, Hwang, et al. (2012) and Wu et al. (2012) developed a sensing technology-supported mobile learning system with a conceptual framework for helping students to experience and learn the nursing measurement procedure and skills. Yin, Song, Tabata, Ogata, and Hwang (2013) proposed a participatory scaffolding using mobile technology for helping students learn conceptual knowledge of a computer algorithm.

4.3.4. Mainly learner control

"Mainly learner control" indicates that the learners learned independently, and teachers provided assistance when the students needed help. For instance, Lan et al. (2012) developed a mobile interactive teaching feedback system to support learners with online problem-based asynchronous discussion. The students who used mobile devices were more engaged in reflective thinking, shared more information, and the system further facilitated social knowledge construction among group members. Hsiao, Lin, Feng, and Li (2010) developed a location-based system that assisted students in observing and constructing knowledge at their own learning pace on an ecological field trip.

4.3.5. Full learner control

"Full learner control" indicates that the learners engaged in mobile learning activities read and collected learning material themselves, and generated knowledge themselves. In the present study, none of the publications was classified into this category.

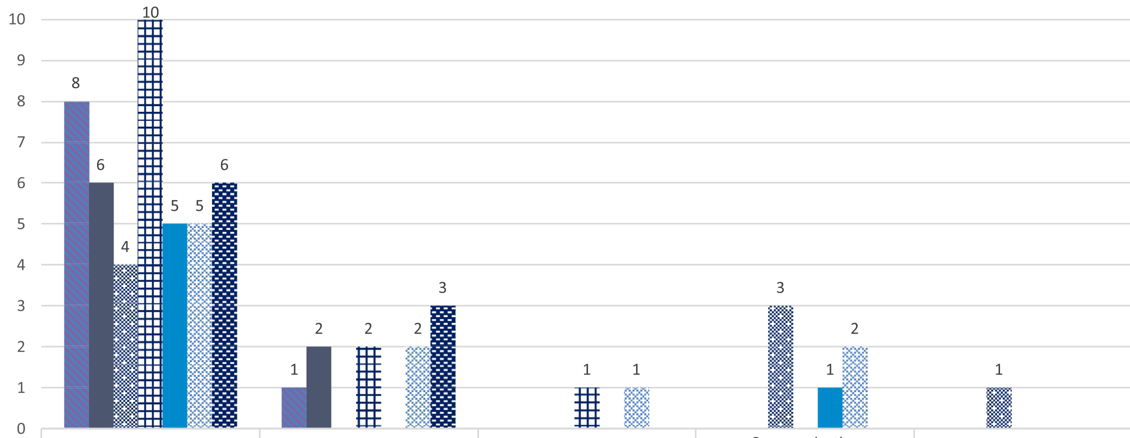
4.4. Communication

With the popularity of social media and their availability on smart devices, collaborative learning has become more interesting; that is, the technologies have facilitated computer-supported collaborative learning by allowing peers and teachers to interact without being limited by location or time (Zurita & Nussbaum, 2007). Through peer interactions and collaboration, reflections can be made, and hence deeper knowledge can be derived. Nevertheless, it was found that mobile devices were considered a main way of allowing students to acquire self-learning materials rather than a mediation learning across contexts. Fig. 5 shows the analysis results based on the "communication" factor. The majority of the studies, 44, involved isolated learners, 10 involved loose couples, two involved tight couples, with six involving within-group communication and one involving cooperation.

4.4.1. Isolated

The factor "isolated" indicates that the system is developed for individual learning, that is, no communication mechanism is provided, implying that individual learners need to complete the learning tasks on their own (Frohberg et al., 2009). For example, Wu, Hwang, et al. (2012) and Wu et al. (2012) developed a mobile learning system based on the cognitive apprenticeship approach for nursing skills training. Each student was asked to practice on his/her own following the guidance and feedback provided by the system.

Although the isolated learning approach could not deepen the learning by discussing, analyzing or working together with others,



	Isolated learners	Loose couples	Tight couples	Communication within group	Cooperation
in 2016	8	1	0	0	0
in 2015	6	2	0	0	0
in 2014	4	0	0	3	1
in 2013	10	2	1	0	0
in 2012	5	0	0	1	0
in 2011	5	2	1	2	0
in 2010	6	3	0	0	0
in 2010-2016	44	10	2	6	1

Fig. 5. Classification of the mobile learning studies by the "communication" factor.

many researchers developed personalized learning paths (Chen & Huang, 2012; Hsu et al., 2016; Wu, Sung, Huang, Yang, & Yang, 2011), or self-assessment systems (de-Marcos et al., 2010; Hwang et al., 2016; Nikou & Economides, 2016) for maximizing their self-learning performance.

4.4.2. *Loose couples*

A system associated with "loose couples" delivers the same learning content and tasks to a group of learners who are required to deal with the learning tasks on their own. The difference is that the learners are guided to interact with peers before completing their own tasks (Frohberg et al., 2009). For example, in Hwang and Chen's study (2013), a listening/speaking practicing system was developed for recommending sample voices recorded by peers. The learning design aimed to encourage the students to have more practice and interaction with peers. Another example of a "loose couple" study was that conducted by Hsiao et al. (2010), who designed and implemented a location-based ecological system. Via encouraging students to share what they had learned, the system enabled them to make reflections and complete their own tasks. In the meantime, Sung, Hou, Liu, and Chang (2010) conducted a problem-solving mobile learning activity which provided an opportunity for students to discuss the problem with their classmates.

4.4.3. *Tight couples*

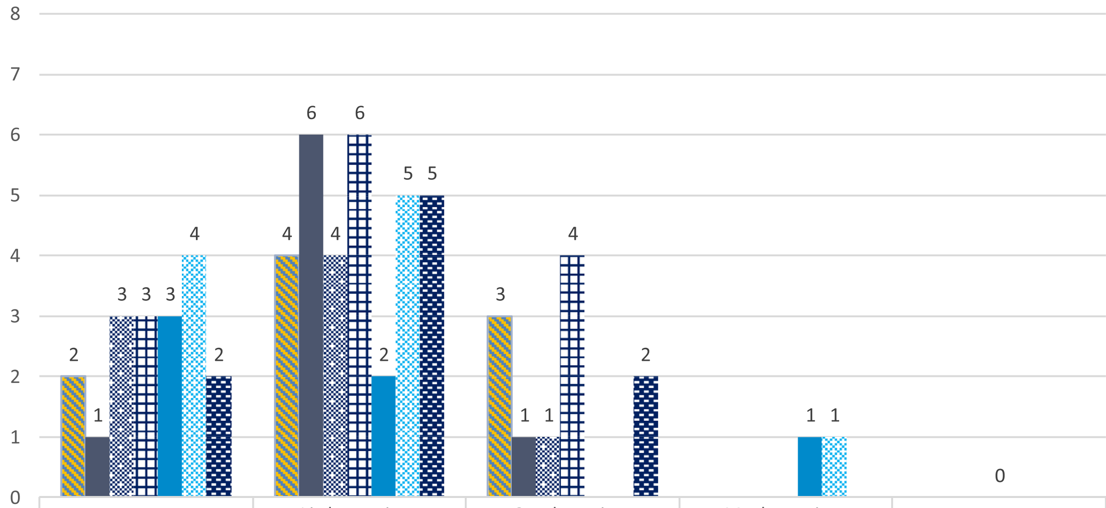
"Tight couples" refers to the strategy that engages a team of students in accomplishing learning tasks together. For example, Chen (2013) developed a location-based book recommendation system for supporting students to cooperate with group members in order to complete their historical reports together in a real-library environment. Huang and Wu (2011) developed a mobile learning system to guide students to learn plant biology in teams and to complete science reports together.

4.4.4. *Group communication*

While "tight couples" refers to the interactions which occur between team members, "group communication" refers to the interactions between groups. This implies a great deal of social interaction during the learning process (Frohberg et al., 2009). For example, Hung, Hwang, et al. (2014) and Hung, Yang, et al. (2014) proposed a ubiquitous problem-based system to assist students' scientific inquiry with their team members; they collected the information in the field and explored, analyzed and reflected on different representations of environmental data. Moreover, each team was asked to share their initial thoughts, inquiry plans, and reports with other teams.

4.4.5. *Cooperation*

The "cooperation" factor refers to the learning design forcing collaboration between teams to complete the learning task (Frohberg et al., 2009). An example is the study conducted by Huang et al. (2014), who introduced a jigsaw-based cooperation learning strategy in a mobile learning activity. The students needed to cooperate with the ones from other teams who were assigned the same task to discuss and find the answers to the tasks. After completing the assigned tasks, they then went back to their own teams



	Novice	Little previous knowledge	Good previous knowledge	Much previous knowledge	Expert
in 2016	2	4	3	0	0
in 2015	1	6	1	0	0
in 2014	3	4	1	0	0
in 2013	3	6	4	0	0
in 2012	3	2	0	1	0
in 2011	4	5	0	1	0
in 2010	2	5	2	0	0
in 2010-2016	18	32	11	2	0

Fig. 6. Classification of the mobile learning studies by the "subject" factor.

to share what they had learned with their team members to complete the final learning task cooperatively.

4.5. Subject & objective

In this subsection, the factors of subject and objective are discussed. According to Fig. 6, it was found that the m-learning environments were frequently used by novice learners (18 studies) or learners with limited previous knowledge (32 studies), such as young pupils, freshmen in colleges or first-time visitors in museums. At this stage, they have not yet developed into subjects targeted for expert or scholarly studies.

Fig. 7 shows the classification of the mobile learning studies by the "objective" factor where the large majority of the studies are classified as "comprehend and know," and the following as "apply." The current empirical research is most focused on lower cognitive abilities, such as "know" (i.e., remember, retain), "comprehend" and "apply."

4.5.1. Novice and little/good previous knowledge

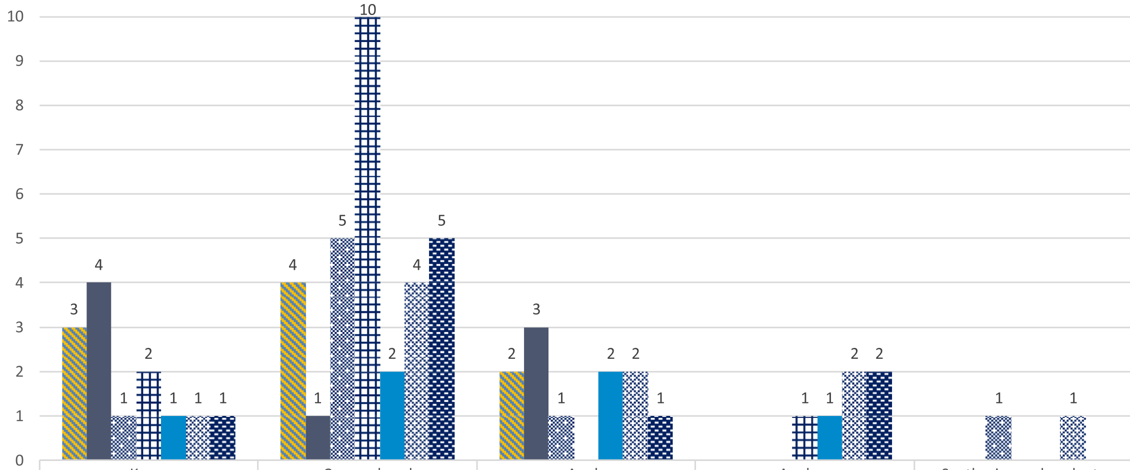
Most of the studies conducted experiments with subjects who were novices or who had little/good previous knowledge. For instance, Huang et al. (2016) developed a learning system for helping fourth grade students learn English vocabulary. Another study conducted by Chen, Liu, and Hwang (2016) aimed to develop a gamified mobile learning system with multi-stage guiding for helping fifth graders identify plants in the field.

4.5.2. Much previous knowledge and expert

Among the studies, only the subjects of a few studies were learners with much previous knowledge. For example, in the study conducted by Wu, Hwang, et al. (2012) and Wu et al. (2012), a mobile learning system was developed for the participants who had received nursing training for years and had sufficient knowledge to practice physical assessment procedure.

4.5.3. Conclusions and summary

Mobile learning aims to construct a learner-centered environment that enables learners to learn, experience, explore and interact with the real-world and/or digital-world resources using mobile or portable devices. This study evaluated and categorized 63 mobile learning studies published in 2010–2016. Most studies were carried out in a physical context, meaning that mobile learning corresponds with the situated learning theory emphasizing that meaningful learning take place in authentic circumstances; that is, it



	Know	Comprehend	Apply	Analyze	Synthesize and evaluate
in 2016	3	4	2	0	0
in 2015	4	1	3	0	0
in 2014	1	5	1	0	1
in 2013	2	10	0	1	0
in 2012	1	2	2	1	0
in 2011	1	4	2	2	1
in 2010	1	5	1	2	0
in 2010-2016	13	31	11	6	2

Fig. 7. Classification of the mobile learning studies by the "objective" factor.

helps the learners transform the experiments to solve similar events in daily life.

However, from a cognitive load perspective, learning tasks conducted in real-world contexts could be too complex to most learners, in particular, novices or inexperienced students (Van Merriënboer & Sweller, 2010; Shadiev et al., 2015); thus, well-designed instruction guidelines or supports were needed to cope with this problem, as indicated by Chu (2014), who showed the potential negative effects of in-field mobile learning activities based on an experiment. Therefore, in addition to evaluating students' learning performances and perceptions, many studies have assessed students' cognitive loads when proposing new mobile learning strategies, such as the ones conducted by Hou et al. (2014) and Yang, Hwang, et al. (2013) and Yang, Tseng, et al. (2013). From the review results, it is found that a number of mobile learning studies were conducted in the field for novice learners or learners with little previous knowledge, and the participants were mostly guided to learn individually in a teacher control mode. This implies that the studies aimed to demonstrate the effectiveness of the proposed mobile learning approaches in improving the participants' learning performances by taking their knowledge levels as well as the issues of cognitive load into account.

In terms of the role of mobile technology as a learning tool, it is found that the number of studies using the mobile technology as a learning content delivery channel is slightly decreased; however, there is still a large portion of studies mainly using the technology to provide learning content. On the other hand, the number of studies using mobile technology to enable guided reflection, reflective data collection and "content construction" is not as many as expected. This is also reflected in the fact that most studies were "teacher controlled" rather than "learner controlled," and hence the "objective" of most mobile learning was to "know" or "comprehend" rather than to "analyze" or "synthesize and evaluate." Therefore, it is suggested that mobile learning researchers need to reconsider how to shift the "objective" of mobile learning from "know" and "comprehend" to "analyze" or "synthesize," and then to try to develop "learner controlled" activities using the technology as a learning tool to help students make reflections, construct knowledge and solve problems.

To sum up, the advancement and popularity of mobile technology has enabled the provision of learning supports for in-field mobile learning activities to improve students' learning performances as well as decrease their cognitive load. The review results have confirmed what has been indicated by several previous studies; that is, that there is too much information to be acquired and analyzed by the learners who need to face both the real-world and digital-world contexts, and hence the provision of proper guidance or supports is required (Chu, Hwang, & Tsai, 2010). The review results show that a number of studies have been conducted in this direction. On the other hand, it was found that there have been few attempts related to "learner control," "cooperation," "socialized context" and "subjects with much previous knowledge." Moreover, mobile devices are still mostly applied for learners to access self-learning materials rather than communication and interaction, not to mention knowledge construction or higher order thinking. Therefore, there is still a very large space for progress and development in the mobile learning field.

In this study, the document analysis mainly focused on the mobile learning modes in which the students were situated. It is suggested that a detailed level of categories can be considered in future studies to provide more specific suggestions, such as learning domains (like math, language, art, etc.) and mobile devices (e.g., smart phones or wearable devices).

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