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DEVELOPMENT ARTICLE

Difficulties in defining mobile learning: analysis, design characteristics, and implications

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Abstract

Mobile learning, or *m-learning*, has become an umbrella term for the integration of mobile computing devices within teaching and learning. In the literature, however, use of the terms has been unsystematic. The purpose of this article is to critically examine the principles of mobile learning. First, I examine the extant literature with regard to defining mobile learning. Four definitions of mobile learning categories are described: (1) relationship to distance education and elearning, (2) exploitation of devices and technologies, (3) mediation with technology, and (4) nomadic nature of learner and learning. Second, in an effort to provide a basis on which to ground future mobile learning research, I propose a framework of design characteristics for mobile learning environments. Seven design characteristics are identified and discussed. Finally, I present implications for future research and instructional design. This paper contributes to the field of mobile learning by providing researchers more precise ways to identify and describe the characteristics of mobile learning environments, as well as describe the attributes of successful mobile learners.

Keywords Mobile learning · Mobile computing devices · Mobile learning environments · Instructional design

In school and at work, mobile computing devices, such as smartphones, cellphones, tablet computers, e-readers, and wearable devices, are becoming important tools for teaching and learning. There has been growing interest in describing, designing, implementing, and evaluating how mobile computing devices are able to facilitate education, training, and performance support (e.g., Ambient Insight, 2010; Attewell et al. 2010; Parsons 2014). Mobile computing devices use mobile data services and mobile applications. Mobile data services include cellular networks, SMS text messaging, GPS location data, and WiFi networks. Mobile applications (i.e., apps) are (a) integrated with the hardware of a device, such as a camera, gyroscope, and accelerometer; and (b) downloaded through marketplaces, such as games, book readers, and context-aware applications (e.g., Musumba and Nyongesa 2013). The rapid expansion of mobile computing devices, data services, and applications together with the concomitant use of the term *mobile learning* or *m-learning*, however, raises

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questions about if and how mobile learning differs from previous and current technology-supported teaching and learning. Moreover, the specific affordances of mobile computing devices, data services, and applications have not been clearly explained.

Mobile learning, however, is one of the topics that has been criticized for focusing on the study of "things" (i.e., the use of mobile computing devices) rather than educational problems (Reeves and Reeves 2015a, p. 27; Reeves and Reeves 2015b) that would improve learning and achieve learners' goals. Reeves and Reeves (2015b) argue that findings from mobile learning research "are hardly compelling and provide insufficient guidance for practitioners" (p. 92) and commonly find no significant differences. One reason mobile learning research may not contribute more to educational technology research is the diversity and surplus of definitions for and implementations of mobile learning. *Mobile learning* and *m-learning* as terms have been used unsystematically, and their meanings have been confused. This confusion may be one reason that systematic reviews continue to report that many mobile learning research studies do not report pedagogical or theoretical frameworks (Bano et al. 2018; Baran 2014; Zydney and Warner 2016). A stronger theoretical foundation for mobile learning is needed. If educational researchers can tighten our definitions of mobile learning, we may be able to identify, describe, and implement the attributes and affordances that we need to measure or explain when there *are* significant effects.

Purpose

While previous researchers and authors have defined mobile learning in various ways, few have examined whether the definitions and accompanying assumptions influence the research, design, practice, and evaluation of using mobile computing devices and mobile data services. This article extends the work of other mobile learning scholars who have questioned the assumptions and foundations of mobile learning (e.g., Brown and Mbati 2015; Parsons 2014; Traxler 2007; Winters 2006). Moreover, a clearer theoretical framework is needed to ground research in the unique affordances mobile learning offers and also guide and frame conclusions for research findings. Furthermore, characteristics are needed to help practitioners in the design of learning environments.

In the remainder of this paper, I address three areas. First, I analyze the extant literature with regard to defining mobile learning. These definitions of mobile learning are categorized and described as four groups. Second, I propose design characteristics for mobile learning environments as a way forward for identifying and explaining affordances. Seven design characteristics are proposed and discussed. Finally, I present implications for future research and instructional design.

An analysis of definitions of mobile learning

To execute the critical analysis, I conducted a literature search to identify and categorize the different ways in which mobile learning has been defined both historically and currently. I focused on studies that defined or operationalized mobile learning in differing ways. I began the literature search using digital databases and indexes (i.e., EBSCO, Education Source, ERIC, WilsonWeb, Google Scholar) with the following terms in combination: mobile learning, m-learning, design principles, characteristics, affordances, definition, operationalization, pervasive, ubiquitous, mobile device, mobile computing,

PDA, cellphone, handheld, wireless, SMS, text, social media, and social networking. I also reviewed (a) recent American Educational Research Association and Association for Educational Communications and Technology conference papers and sessions dedicated to mobile learning (e.g., Joo et al. 2013; Kim and Kim 2013; Martiz 2013; Uzan et al. 2013), (b) chapters throughout the *Handbook of Mobile Learning* (Berge and Muilenburg 2013) and *The New Landscape of Mobile Learning* (Miller and Doering 2014), (c) seminal authors in the field of mobile learning (e.g., Ally, Crompton, Koole, Kukulska-Hulme, Sharples, Vavoula, Traxler), (d) existing literature reviews and meta-analyses (e.g., Crompton et al. 2017; Krull and Duart 2017; Langer et al. 2014; Liu et al. 2013; Nguyen et al. 2015; Sung et al. 2015a; Wong and Looi 2011) and (e) references cited within the articles reviewed (i.e., reverse bibliographic search). This process broadly followed a qualitative thematic analysis.

I categorized articles and studies by definitions and characteristics of mobile learning. Design principles or guidelines were also noted across a number of articles. Researchers and authors referenced and grounded their works within a small number of definitions and principles. Saturation occurred when no new categories or groupings were coded, and new data (i.e., authors, definitions, characteristics, design guidelines) were assigned to existing categories (Charmaz 2003). Trustworthiness of these findings was vetted by exposing my descriptions and categories to evaluative peer review (Bowen 2008) on multiple occasions. Also, the findings were shared, and I invited feedback as part of a roundtable presentation at the American Educational Research Association annual meeting in 2014.

The present categories encompass and extend those by Winters (2006). Previously, Winters detailed four perspectives of mobile learning definitions as technocentric, relationship to e-learning, augmenting formal education, and learner centered. As expected, the *technocentric* perspective focused on the mobile devices specifically. The *relationship to e-learning* perspective was criticized as ignoring the specific affordances of mobile learning. The *augmenting formal education* perspective made connections to using mobile devices in face-to-face instruction. Lastly, the *learner-centered* perspective placed emphasis on the movement of the learner across contexts. Many of these perspectives persist in current definitions of mobile learning and in research, so Winters framework as a basis is still quite relevant.

From the literature search and thematic analysis, four categories of definitions emerged. Here, each category is described with regard to assumptions, limitations, and comparisons to previous technology-supported learning topics. The four categories of mobile learning definitions are (1) relationship to distance education and elearning, (2) exploitation of devices and technologies, (3) mediation with technology, and (4) nomadic nature of learner and learning. Note that the categories are not necessarily mutually exclusive to one another, and the authors may mention more than one category in their discussions or operationalized research. The four mobile learning categories are summarized in Table 1.

Relationship to distance education and elearning

A number of definitions have described mobile learning as a relationship to distance education and elearning. Quinn (2000) broadly described mobile learning as "the intersection of mobile computing and elearning: accessible resources wherever you are, strong search capabilities, rich interaction, powerful support for effective learning, and performance-based assessment. eLearning independent of location in time or space

Table 1 Definitions of mobile learning

Category	Characteristics	Example authors
1. Relationship to distance education and elearning	Uses resources, experts, and information searches at the time of learner's need Analogous to web-based learning	Harris (2001), Liu et al. (2010), Motiwalla (2007), Ugur et al. (2016), Ozuorcun and Tabak (2012), and Quinn (2000)
2. Exploitation of devices and technologies	Highlights the uses of devices and networks to support teaching and learning	Mobile Learning Network (MoLeNET) (2009 and Wagner and Wilson (2005)
3. Mediation with technology	Focus on how interactions with environments and individuals are mediated (or facilitated) using mobile computing devices and mobile data services	Han and Shin (2016), Herrington and Herrington (2007), Kearney et al. (2015), Mouza and Barrett-Greenly (2015), and Wu et al. 2012)
4. Nomadic nature of learner and learning	Learners not in predetermined or common location Learning anytime, anyplace, and between areas of life Ubiquity of learning across contexts	Kiger and Herro (2014, Krull and Duart (2017), Ng et al. (2010), O'Malley et al. (2003), and Reychav et al. (2015)

[sic]" (Introduction section, para. 8). This has been historically and commonly considered the first definition of mobile learning. Unfortunately for scholars and practitioners, there has not been a consensus for a single definition of *elearning*. Instead, *elearning* is used broadly and connotatively with terms such as tele-learning (Collis 1996), online learning (McNaught et al. 2012; Salmon 2000), and distributed learning (Bates 2000; Khan 2005). Clark and Mayer (2003), however, defined elearning to include any purposeful and meaningful instruction delivered by a computer, and more recently, Ozuorcum and Tabak (2012) defined elearning as "using technological devices and the Internet for teaching and learning" (p. 301).

With small differences, many researchers and authors have continued to use the relationship to distance education and elearning to define mobile learning (e.g., Georgiev et al. 2004; Harris 2001; Keegan 2005; Y. Liu et al. 2010; McGreal 2009; Motiwalla 2007; Ugur et al. 2016; Ozuorcun and Tabak 2012; Ting 2013). These authors have subscribed to a pedagogical stance that mobile learning affords the same characteristics set forth by Quinn, which is the intersection of mobile computing and elearning. That stance has been typified by Georgiev et al.'s (2004) graphic (see Fig. 1).

Researcher Simon So (2010), however, questioned definitions of mobile learning based on elearning. He posited that mobile learning and elearning were more likely derivations of distance learning instead of subsets of distance learning, sharing specific traits but also retaining unique characteristics (see Fig. 2).

For example, So (2010) questioned the instructional necessity of requiring a mobile device at all in some cases. He has challenged us to consider whether language learning recordings on a smartphone application is any different than playing a language learning CD while driving. As Krotov (2015) claims, this perspective has made it difficult to argue that mobile learning is "a new approach to education" (p. 106). Moreover, researchers have argued that mobile learning should not be viewed as an alternative to delivering elearning content (Haag and Berking 2015; Queirós and Pinto 2014); mobile learning should offer unique value beyond a deployment method. Therefore, when authors suggest that mobile learning has been a subset of elearning or distance education, they have in many cases focused on the devices and technologies instead of an educational problem, such as providing access to education. Winters (2006) and Traxler (2005) suggested that emphasis on elearning simply considers mobile learning with

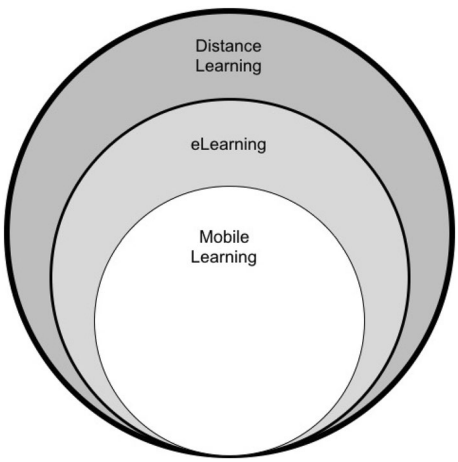

Fig. 1 Mobile learning as a subset of distance learning and e-learning

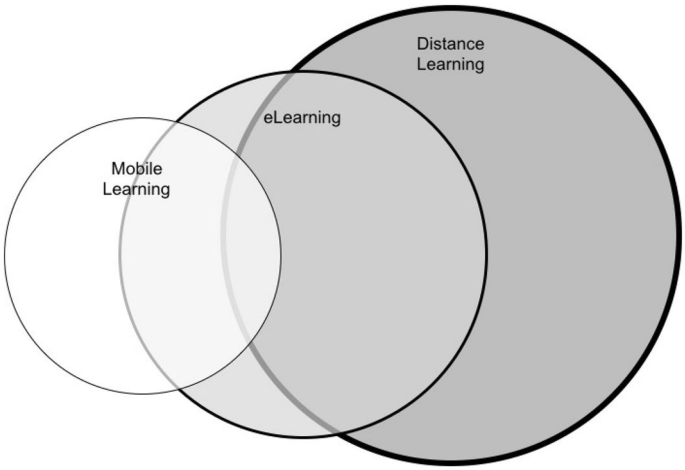

Fig. 2 Mobile learning, elearning, and distance learning's intersecting relationships Adapted from So (2010)

regard to "portability" (Traxler, 2005, para 12). Two of the three remaining categories begin to address the unique affordances of mobile learning.

Exploitation of devices and technologies

The second emergent category focuses on mobile computing devices and mobile data services. Other authors have emphasized the use and exploitation of devices and technologies for mobile learning. Winters (2006) labeled this category of definitions as "technocentric" (p. 4). Wagner and Wilson (2005) have emphasized that mobile learning "takes advantage of ubiquitous networks and pervasive digital devices" (p. 42). Keegan (2005) in an attempt to simplify others' complex definitions wrote that mobile learning could not include laptop computers. Instead, mobile learning was restricted to "devices which a lady can carry in her handbag or a gentleman can carry in his pocket" and "the provision of education and training on PDAs/palmtops/handhelds, smartphones, and mobile phones" (Keegan 2005, "2. Definition of Mobile learning" section, para 3). The Mobile Learning Network (2009) identified mobile learning as the "exploitation of ubiquitous handheld hardware, wireless networking and mobile telephony to facilitate, support, enhance and extend the reach for teaching and learning" ("What is Mobile Learning" section, para. 1). Some of these definitions that focus on exploiting new technologies have included both mobile devices and mobile data services, such as cellular networks, SMS text messaging, or GPS data. This category encompasses Winters' (2006) perspective of augmenting formal face-to-face instruction, which may not include any movement by a learner such as using audience polling during a lecture.

This focus on devices and technologies, however, has limitations. Traxler (2010) has asked scholars and practitioners to disregard any definitions that have been based on technologies or devices. Similarly, Krotov (2015) has argued that technology- or device-centric definitions restrict progress and "novelty" (p. 106). That is, these definitions will become obsolete. Emphasizing mobile technologies or devices has disregarded other sociocultural

elements of a mobile learning environment (Koole 2009; Krotov 2015; Mouza and Barrett-Greenly 2015), such as the learner, the context(s) in which learning occurs, tutors, and whether the learning is initiated by the learner or compulsory within a course/training.

Mediation with technology

A related but distinct category of definitions is the use of technology as a mediator or facilitator for teaching and learning. The emphasis in this category is on interactions among the learner, the technologies, and the environment. Russell (2001) has defined mediation as individuals' interactions with others, rules, and tools to broadly solve problems. Mediation has also reflected how an individual's understanding of a problem space (i.e., his environment or context) is affected (Russell 2001). For example, a group of high school students may use group text messaging applications, their mobile phones, and either Wifi networks or cellular networks to ask questions to one another while completing their geometry homework. Within the group, individuals may take turns providing support and tutoring. Each individual's zone of proximal development may be met at differing times by others in the group. Social group norms/rules are maintained as each student responds; expectations for the discipline (i.e., geometry) and from the teacher are maintained as well. These interactions are mediated through the mobile computing devices, mobile data services, and applications.

Herrington and Herrington (2007) defined mobile learning as learning that is "mediated through a mobile device" ("Some current uses of mobile technologies" section, para 1). Kearney et al. (2015) extended this definition to include mediation "by handheld devices such as smart phones, tablet computers and game consoles" (p. 48). Similarly, Wu et al. (2012) broadly defined mobile learning with a "mediating tool for learning" (p. 818). Mouza and Barrett-Greenly (2015) associated mediation with interactions among learners, mobile computing devices, and a learning environment.

This category of definitions draws attention to learners' interactions with mobile computing devices within a learning environment. That is, individual learners are autonomous within their environments, engage with their environments, and exert control over their environments (i.e., have agency) (Biesta and Tedder 2007; Russell 2001). While these authors' definitions highlight the interactions with mobile computing devices, mobile data services, and individuals, they do not necessarily address the importance of a context or fluidity across contexts.

Nomadic nature of learner and learning

In the last emergent category of mobile learning definitions, Vavoula and Sharples (2002) have emphasized the nomadic nature of mobile learning, focusing on the learning and not necessarily the learner or the device. Vavoula and Sharples suggested that mobile learning can occur anywhere, anytime, and between the areas of life. O'Malley et al. (2005) suggested mobile learning occurs when the learner is not in "a fixed, predetermined location" (p. 7). They distinguish between learning that is in a usual place, such as home, office, or classroom, and learning that is away from usual places. However, they emphasize that if a learner is mobile then learning can occur in any place. Therefore, learners can access and integrate knowledge and resources from multiple

sources (i.e., connectivism; MacCallum et al. 2017), as well as disperse learning processes across a group of individuals and store this knowledge for later use within a mobile device (i.e., distributed cognition; Hollan et al. 2000).

Ng et al. (2010) distinguished between mobile learning and pervasive learning. Mobile learning "is not constrained by space or time," and pervasive learning is embedded across "all aspects of the students' lives and could take place anytime and in between other activities" (Ng et al. 2010, p. 53). However, Ng et al.'s definitions for mobile learning and pervasive learning have seemed to overlap with the other definitions in this category that emphasize the characteristics of anytime, anywhere learning. Pervasive learning has been described similarly to ubiquitous learning (see Reychav et al. 2015), where learning is continuous and mobile computing devices allow learners to communicate at any time or place. When advocating for anytime, anywhere learning, scholars have emphasized learners' autonomy to meet their own goals and schedules.

Anytime, anywhere learning, though, has been previously associated with online education (e.g., Bourne et al. 2005; Hong et al. 2003; Kanuka et al. 2007), laptop computer implementations (e.g., Gulek and Demirtas 2005; Ito 2003), personal and professional learning (Ivanova 2009; Saadatmand and Kumpulainen 2013), and technology integration (e.g., Huffaker 2004). The notions of learning initiated by a learner (i.e., learner autonomy, self-directedness) and continuous access to learning contents, information, and resources have not been unique to mobile learning. Krotov (2015) noted that in a crude form "carrying around books, notes or prerecorded lesson [sic] on tape" can be anytime, anywhere learning (p. 106). Thus, asserting that mobile learning affords faster, more convenient, or geographically fluid opportunities does not support a new approach to education.

In addition, we must recognize that not all anytime, anywhere interactions with mobile devices and data services are intended to support learning; some interactions may be performance support (Traxler 2007). There are many instances in which individuals may not need to retain or integrate new knowledge. For example, a quick search inside a restaurant review app can provide the location, average price of entrees, and ratings by customers. Once a restaurant is chosen, however, this new knowledge need not be retained and may be forgotten. In these instances, learning and retention are not the goal. Instead the purpose is to support accomplishing a task at hand (Rossett 2010). Therefore, anytime, anywhere is not limited to only mobile learning opportunities. However, the movement of a learner and self-directed actions across a context suggest a uniqueness for mobile learning.

Conclusions

Individually, these categories of definitions seem problematic. The definitions in many cases do not represent the affordances of learning while mobile. In some cases, the definitions are simply inadequate. With mobile learning, there is a need to clearly delineate *what is* and *what is not* mobile learning research. By continuing to use *mobile learning* as a catch-all term unsystematically, researchers and scholars are subject to inadequately designing, implementing, or evaluating educational problems of substance. Thus, I argue that definitions of mobile learning should be disregarded as theoretical operationalizations for research. Instead, design characteristics that are essential to mobile learning environments are proposed in the following section.

Design characteristics of mobile learning environments

To move the field of mobile learning research forward, a theoretical framework is needed that addresses Clark's (1983) and Herrington et al.'s (2010) requirement that educational technology research should identify the unique active ingredients within a learning environment. In the following paragraphs, I propose that future research and implementations define mobile learning environments that positively impact learners' goals (e.g., access to education, learning from and in specific contexts, learning across different times) with design characteristics focused on affordances. Previous reviews (Bano et al. 2018; Baran 2014; Zydney and Warner 2016) have noted that many studies have either not relied on frameworks to design or implement mobile learning or failed to report the frameworks used. The design characteristics presented here differentiate essential features within a mobile learning environment and address the specifics of learning or instructional goals.

As part of the literature review process when examining definitions, design characteristics were also collected, reviewed, and organized. Like the definitions previously presented, there were repeating patterns of characteristics used when scholars were describing implementations of mobile learning. Design characteristics have been used to reflect a planned learning design (Herrington et al. 2009; Van den Akker 1999); they help to inform practice by informing design. The design characteristics presented here evolved from previous authors. For example, Klopfer et al. (2002) defined the affordances of mobile devices as portability, social interactivity, context sensitivity, connectivity, and individuality. Roschelle and Pea (2002) identified similar affordances while emphasizing mobility of learners was critical. Herrington et al. (2009) have identified the following design characteristics for mobile learning: real world relevance, mobile contexts, exploring mobile technologies, blending mobile and non-mobile technologies, using mobile spontaneously, using mobile learning in informal learning spaces, using mobile learning individually and collaboratively, exploiting affordances of mobile technologies, using learners' personal devices, mediating knowledge construction, and using mobile learning to produce and consume knowledge (p. 134). Finally, Stanton and Ophoff (2013) identified social interactivity, context sensitivity, personalization, ubiquity, and nomadicy.

The design characteristics summarized in Table 2 are recommended to inform the design of mobile learning environments in order to state unique affordances with mobile learning and address learning goals. The seven characteristics are placed on continua in Fig. 3 to depict the scope and variation of the individual characteristic, and I propose a new framework for identifying the active ingredients within a mobile learning environment. A foundational assumption for this framework is that all of these characteristics are required of mobile learning environments. The extent or ways in which the characteristics are employed certainly vary. The use of continua presents that there are varying degrees to each of these characteristics, meaning there would be many possible variations of mobile learning environments. Each design characteristic is discussed further below.

Learner is mobile

This design characteristic represents the extent to which the learner is mobile within a learning environment. The continuum for this design characteristic considers the extent to which learners move autonomously across times and spaces. In some mobile learning environments,

Table 2 Summary of design characteristics of a mobile learning environment

Design characteristic	Summary
Learner is mobile	A learner employing key learning characteristics of learner autonomy, self-regulation, self-directedness, and metacognition
Device is mobile	A mobile computing device, such as a smartphone, feature phone, tablet computer, and imminent wearable technologies with the ability to access data networks and data services that may act as a scaffold as social, metacognitive, or cognitive tools
Data services are persistent	Persistent data and network services, including Wifi and cellular networks but also considers developing networks and connections for Bluetooth, radio frequency identification (RFID), and near field communications (NFC)
Content is mobile	Learning contents, including formal instruction or training, resources, media, data; learning goals for informal learning environments that are primarily at the direction of the learner; or performance and decision supports to aid individuals at the time of need
Tutor is accessible	A tutor, also described by Vygotsky as "more knowledgeable other," such as a teacher, facilitator, mentor, peer, coach, networked expert, intelligent tutor, or pedagogical agent
Physical and networked cultures and contexts impact learning or learner	A description for how physical and networked cultures and contexts impact the learner and the characteristics of the learning
Learner is engaged	A description of the method(s) for how the learner engages with the characteristics of the mobile learning environment for formal, informal, or semi-formal learning

the learner may be stationary, moving little in his or her environment, which is common in formal learning settings like K-12 and higher education classrooms. Mobile learners, particularly with informal learning, can also be physically and socially separated from peers and teachers. So mobile learning scholars assert that key learner characteristics are required for individuals to be effective. Tella (2003), Ng et al. (2010), and Strong et al. (2013) agreed that mobile learning affords learner autonomy and requires self-direction; however, requirements for self-direction in formal learning has not been consistent (Bartholomew et al. 2017). Learner autonomy has reflected an individual's agency for learning and desires or motivations to achieve individual goals (Liaw et al. 2010; Sha et al. 2012a). Similarly, self-direction has reflected an individual's analysis of current or future learning needs with the resources and strategies necessary to accomplish these needs (Knowles 1975). Sha et al. (2012a, b) in particular argue that the ubiquity of mobile learning opportunities, that is learning across times and spaces, necessitates self-regulation. Self-regulation by learners has involved the use of goal setting, strategy selection and use, self-monitoring, and evaluation (Cohen 2012; Dunn et al. 2014). Autonomous learners in mobile learning environments are required to navigate through informational resources and determine their utility (Brown and Mbati 2015; Cui and Roto 2008; Koole and Ally 2006).

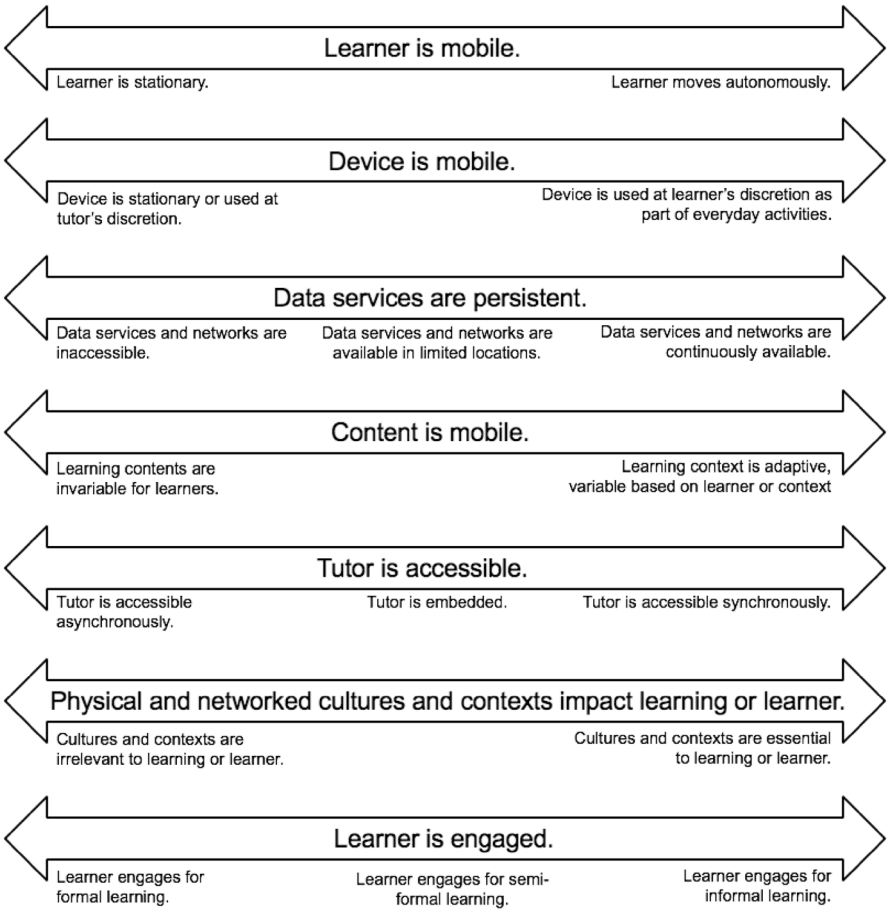

Fig. 3 Design characteristics in a mobile learning environment to address an educational problem

Device is mobile

In mobile learning research, scholars commonly referred to the term *mobile* to describe movement, or more specifically the fluidity and flexibility of mobile devices in our lives. In some limited uses of mobile devices, the devices are primarily stationary and used at the discretion of the tutor. For example, K-12 schools have implemented classroom sets or carts of mobile devices (e.g., Crompton et al. 2017; Grant et al. 2015; Mouza and Barrett-Greenly 2015). In their classrooms, K-12 students have collaborated with peers, created representations of their knowledge, and accessed help from peers, online sources, and their teachers. In these cases, the teacher often has determined when and how mobile devices will be used, and the students may be unable to take the devices home (e.g., Ciampa 2014; Greenberg 2010; Kiger 2012; Saudelli and Ciampa 2016). The devices have been primarily substitutes for larger computers.

In other instances, mobile computing devices are part of everyday activities and used at learners' discretion. Mobile devices have allowed individuals to fluidly move among multiple communities, both physical and networked. For example, Attenborough and Abbott

(2018) describe their participants' successful and challenging uses of mobile devices for their coursework on campus and then within their clinical healthcare settings. Also, Cochrane et al. (2017) describe the implementation of mobile virtual reality simulations deployed to smartphones.

Data services are persistent

Basole (2004) discussed the value of *mobile* in terms of connectivity. Specifically, mobile data networks (e.g., Wifi, cellular, Bluetooth, NFC) have connected learners to devices or services, devices and services to other devices and services, and learners to other individuals. However, some applications function without a constant connection to a network. This continuum begins with apps and device functionality (e.g., video recording, audio recording) that require no network or data services. The Federal Aviation Administration has begun to allow mobile computing devices to be used continually during flights while in Airplane mode, which suspends the availability of cellular and wireless networks. This disruption in network access reflects the division of functionality between devices and network connections.

The continuum of persistent data services includes limited access and continuous availability. Limited access is evident when learners are restricted by network boundaries, such as locations of Wifi access points within a community or cellular network tower locations. At a recent professional conference, I observed colleagues from the Netherlands who did not have an international cellular data plan, so they were limited to using the networks and data services only when they were within an open Wifi network. Of course, data services and networks can also be continuously available, affording persistent network access and allowing learners to employ many of the other design characteristics, such as accessing geotagged sounds, images, and videos during field work (Jarvis et al. 2016).

Content is mobile

This continuum considers the extent to which learning content is variable or flexible. Some didactic instruction, training, and games present learning content without variation and regardless of the learner or context, for example, the mobile virtual reality simulations mentioned earlier. It is possible to use mobile devices to deploy complete formal units of instruction and learning activities. For example, Grant and Barbour (2013) describe a small study with an online advanced placement (AP) European History course, where the content was developed for mobile deployment. Two of the 26 units in the course were completed through a mobile application *Mobl21*.

Learning content can also vary, or adapt, within a mobile learning environment. This has most frequently been implemented by adapting based on context and/or the learner. For example, in a mobile learning game (Raessens 2007), learning activities were dependent on GPS coordinates and learners had to reconcile historical data with real-time locations. Other examples where this type of adaptivity has taken is in place-based or location-based learning, where specific learning goals and contents are tied to a precise geographic location (Jarvis et al. 2016), such as a nature preserve (Zimmerman and Land 2014), location-based games (Edmonds and Smith 2017), and learning activities designed with context-aware augmented reality layers (Chang et al. 2013; Furió et al. 2015; Hwang and Wu

2014). Other possible adaptation may include navigation and control; assessment, support, and feedback; learning activities; and interface (Inan et al. 2011).

Tutor is accessible

Along this continuum, the term *tutor* is used to encompass Vygotsky's "more knowledgeable other." A tutor can include a teacher, facilitator, mentor, peer, coach, or networked expert, along with expertise embedded inside of apps, such as an intelligent tutor, pedagogical agent, or artificial intelligence. Gikas (2011) reported that as she began her research, Google did not index any entries that specifically addressed mobile teaching. Mobile learning environments must recognize the teacher or tutor in formal learning. Experts and tutors as part of communities of practice or professional learning networks have also filled this role. In the proposed design characteristics of a mobile learning environment, a distinction has not been made between a teacher or facilitator who is actively present, such as in a course or an outdoor science center, and one that is totally programmed into a learning environment, such as a tutor or pedagogical agent (e.g., Nye et al. 2014) or smart assistant (e.g., Apple Siri, Amazon Alexa). Instead this initial operationalization of mobile learning environments emphasizes the need to recognize and consider how teachers, facilitators, or tutors impact learning.

In addition to the type of tutor, this continuum represents temporal mobility (Kakihara and Sørensen 2001) between the tutor and the learner. Temporal mobility reflects the extent to which a learner is separated by time, which is the basis for anytime learning. We are able to achieve temporal mobility with asynchronous communications, such as email, social media, and SMS text messaging. There is an inherent desire, however, for these communications to become closer to real time, such as when senders become frustrated because receivers do not respond immediately. Synchronous access to a tutor can occur when the tutor and the learner are together at the same time (and same place). However, synchronous tutors can also include the programmed tutors within an app, providing scaffolding, decision-making support, or suggestions.

Physical and networked cultures and contexts impact learning or learner

This design characteristic reflects to what extent the physical and networked cultures and contexts impact the learning or the learner. In some mobile learning environments, the cultures and contexts may be irrelevant to the learning and the learner. While the learner may be able to move about while using the device, access data and networks, or use content embedded within an app, the location of the learner, the device, or the content may not impact learning. For example, Alcázar et al. (2018) described the use of mobile serious games for individuals with cognitive disabilities where the games may be played at any location.

In contrast, Koole and Ally (2006) asserted that "cultural settings affect a learner's ability to understand, integrate, and interpret" new knowledge (p.4). This has contextualized learning and has allowed learners to situate knowledge in specific contexts (Brown et al. 1989; Lave and Wenger 1991). Mobile computing devices and mobile data services have afforded social and cultural participation (Roschelle et al. 2007). Learners have

appropriated mobile devices, data services, and applications for their own social practice (Bar et al. 2016). For example, a growing area for mobile learning has been mobile assisted language learning (MALL) (see e.g., Brown 2014; Persson and Nouri 2018; Sung et al. 2015b; Tai 2012). MALL environments have leveraged mobile technologies for situated learning opportunities (Back, 2011; Kukulska-hulme, 2013). For example, in Brown's (2014) research, one faculty member asked students to use the app SnapChat during their daily lives when they engaged in products or food from the target countries. Students then captioned the photos in the foreign language and submitted them to the instructor. The design of a mobile learning environment can incorporate social and cultural aspects of the learning environment and the learner (Sharples 2000).

Learner is engaged

The final design characteristic depicts how learners engage with a mobile learning environment. This characteristic is reflected in learners' motivations for learning, which are indicative of formal, informal, and semi-formal learning. Formal learning occurs when students are engaged with materials developed by a teacher (Colley et al. 2003; Halliday-Wynes and Beddie 2009). It is typically led and evaluated by an instructor (Jubas 2010). For example, Hsu and Ching (2012) reported integrating mobile microblogging into a graduate-level online graphic design course. The students used the on-device camera to take photos of design examples and to share these with classmates, as well as short critiques.

Informal learning was defined by Halliday-Wynes and Beddie (2009) as learning "from daily work-related, family or leisure activities" p. 3) and learning "which people do on their own" (Hrimech 2005, p. 310). Informal learning is sometimes "unanticipated, unorganized, and often unacknowledged, even by the learner" (Jubas 2010, p. 229). Activities, such as reading, using the Internet, visiting community resources, such as libraries, museums, and zoos, and on-the-job learning have been considered informal learning activities. These activities have been typically initiated by the learner himself, so there was often more intrinsic motivation associated with events (Eshach 2006). Cui and Roto (2008) have described types of information seeking with mobile devices in everyday life: Individuals have used mobile devices for (a) fact-finding, where they seek out a specific piece of information, such as the price of clothing while on the bus, and (b) information gathering, where they collect information from multiple sources to compare or aggregate the information in order to make a decision, such as the price of a piece of clothing at multiple stores.

Koole (2009), Roschelle et al. (2007), and Impedovo (2011) have asserted that mobile learning blurs the lines of formal and informal learning, or at the very least, links informal learning to formal learning, referred to here as semi-formal learning. Barron (2006) acknowledged compulsory formal learning can sometimes lead to informal learning, where an individual's interests are piqued for further investigations. For example, Pimmer et al. (2014) described how nurses and nurse educators in South Africa connected workplace learning with their formal educational experiences. Pimmer et al. mentioned the use of mobile phones and a Facebook group to share and reflect on on-the-job practice within their formal education coursework in rural settings. Similarly, GeoJourney (see BGSU-Monitor 2007 http://www.geojourney.org) depicted an undergraduate field-based geography course at Bowling Green State University. In the course, students traveled across the U.S. to geophysically and historically geographic sites. Students prepared between stops with iPods and smartphones packed with slides, videos, and documentaries designed and

organized by faculty members. Thus, formal instruction blended with more informal learning between the prepared learning contents, onsite activities, student interests, data recordings, and reflections for each of the sites. This type of instruction and learning reflected both formal elements and informal elements for mobile learning, indicated as semi-formal learning in Fig. 3. This operationalization differs with Bano et al.'s (2018) use of semi-formal learning as out-of-classroom settings defined primarily as locations.

Figure 4 presents a visual to reflect the design characteristics and interactions for a mobile learning environment.

Future research and implications for instructional design

I have examined how mobile learning has been defined and argued for more precision in operationalizing mobile learning research. This precision has been approached by identifying the design characteristics of a mobile learning environment to address learning goals. There are opportunities to determine which areas of mobile learning environments research are still needed to corroborate, investigate, describe, and confirm and also what should be considered when designing and implementing these innovative and evolving learning environments.

Within the framework of a mobile learning environment and the embedded design characteristics, a number of initial questions exist, assumptions to be addressed, that should be considered as opportunities for future exploration and investigation. For example:

- What are the impacts to the learner or the learning when the tutor (i.e., teachers, facilitators, trainers, peers, mentors, networked experts) is mobile? In what ways do variants in temporal mobility and geographic mobility affect learning with synchronous, asyn-

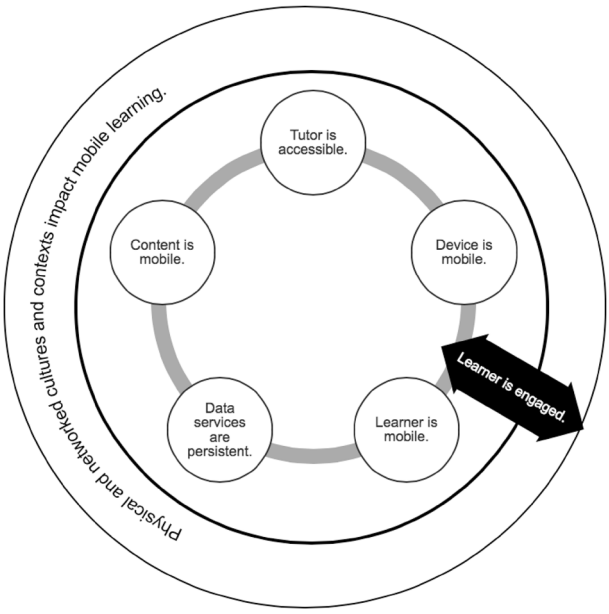

Fig. 4 Interaction of design characteristics in a mobile learning environment to address learning goals

chronous, and embedded tutors. Do mobile learning environments support learner's goals more effectively or efficiently the closer tutor support is to real-time?

- What are the impacts to the learner or the learning when the device is mobile? In what ways has a learner appropriated the device and data services for his own goals? In what ways does the device reflect different sociocultural experiences, tools, or norms? In what ways does the device mediate these experiences?
- How do persistent data services impact learning? How do we distinguish this from online learning? If persistent data services are unnecessary, are the learner and the learning contents still able to be mobile?
- What are the impacts to the learner, the learning, or tutor when the learning content is mobile? Does the learning content change based on location or context? Is the learning content adaptive to contexts, learners, or speeds of networks?
- How does the description of physical and networked cultures and contexts impact the learner or the learning? How does the physical context impact the mobile data services or the learning contents?
- What are the methods by which learners can engage with tutors, mobile computing devices, data services, or learning contents? How does the learner engage with the physical or networked contexts? Which methods are more effective, efficient, or appealing? Which methods are context dependent?

More specifically, I present below four broad areas to suggest further lines of research, as well as implications for instructional designs. The first three topics are expanded from El-Hussein and Cronje's (2010) beginning typology for understanding the evolving field of mobile learning: (a) mobility of technologies, (b) mobility of learning, and (c) mobility of the learner. A fourth topic, (d) research designs, suggests areas for improvement from existing mobile learning research.

Mobility of technologies

The first broad area that offers implications for further research is mobility of technologies. The mobility of technologies includes both the functionality (e.g., video cameras, GPS, ebook readers) and the affordances (see e.g., Grant and Hsu 2014; communications, searching, creation, sharing, curation, aggregation, entertainment, personal organization) inherent to mobile computing devices. In Fig. 3, the mobile devices and the mobile data services have been separated in order to better depict these technologies distinctly. Because some applications function without a constant connection to network, it is essential to study these independently as well as together. In addition, this differentiation in functionality highlights a concern in some K-12 research (e.g., Grant & Barbour, 2013) for the costs associated with cellular data plans and the lack of widespread coverage of cellular networks.

Considering functionality of mobile devices, Cheon et al. (2012) have identified that portability of mobile devices and instant connectivity through mobile data services have been unique to mobile learning environments and have afforded mobile learners significant advantages. Both longitudinal studies and ethnographic studies are needed with different disciplines about how individuals use their devices and access mobile data service to support formal schoolwork and workplace learning, as well as informal, everyday learning.

With technology affordances, technology appropriation (Pachler et al. 2012; Riemer and Johnston 2012) is also a lens through which research may consider the ways in which learners may use mobile data services for their own purposes, such as informal learning, self-regulation, and posts to social media. Studies from social network analyses (e.g., Sun et al. 2018) should be replicated with a mobile learning environment lens. Are there patterns of interactions with more knowledgeable others, available social networks, and available data services networks? In addition, there may be negative affects with the ubiquity of mobile computing devices. This may especially be the case in formal learning environments (e.g., Pedro et al. 2018), but additional research is needed.

Furthermore, Anderson (2015) has reported that in the U.S. a small but significant number of low income and minority young adults are smartphone dependent. Smartphone dependency is when an individual does not have readily available access to broadband Internet at home and is dependent on a cellular network for primary access to the Internet. Napoli and Obar (2014) have termed this *mobile internet underclass* as a new dimension to digital divides. Much more research should be conducted with these individuals to determine how they are using their devices, how they choose their devices, and if they limit their uses based on their data plans.

Mobility of learners

A second broad area offering implications for further research is mobility of learners. El-Hussein and Cronje (2010) emphasized the flexibility and personalization afforded by mobile devices and persistent networks to learners. Experiencing informal mobile learning, however, may put considerable strain on cognitive resources. For instance, learning informally may produce fragmented knowledge (Traxler 2010). While learning in situ and across multiple networked communities, there is justifiable concern that isolated and disconnected knowledge will become inert (Bereiter and Scardamalia 1985), unable to be generalized or integrated into existing schemata. Knowledge and context-dependent skills must be transferred across disciplines or domains to increase their uses. Research should consider what role context plays in mobile learning environments and mobile learners' abilities to integrate knowledge and skills learned across varied contexts. This may be especially important when implementing connectivist (MacCallum et al. 2017) or distributed learning (Hollan et al. 2000) theories.

One area suitable for investigation is scaffolding within mobile learning environments. Hill and Hannafin (2001) have suggested there are four types of scaffolds key to learning in information-rich environments, such as mobile learning environments. Conceptual scaffolds assist learners in deciding importance or features. Metacognitive scaffolds "help learners assess what they know and what to do as they learn" (p. 45). Procedural scaffolds aid learners in using different resources and information, and strategic scaffolds provide support for alternative methods to accomplish tasks. Are there scaffolding mechanisms in mobile learning environments that designers could develop to support learning and reduce cognitive load (see e.g., Belland 2013, 2014)? Are there strategies with regard to scaffolding that individuals already implement during formal learning or everyday lives, such as offloading certain knowledge into their mobile devices, taking photographs of notes and slides, or recording memos into their smartphones to be reviewed later?

Mobility of learning

A third broad area with implications for further research is the mobility of learning. Learning while mobile has afforded authentic situated opportunities (Zydney and Warner 2016). This type of learning is unique "because it is received and processed within the context in which the learner is situated" (El-hussein and Cronje 2010, "Mobility of learning" section", para. 1). This has been particularly true in place-based or location-based learning, where specific learning goals and contents are tied to a precise geographic location such as a nature preserve (Zimmerman and Land 2014) and learning activities designed with augmented reality layers (Chang et al. 2013; Ozdemir et al. 2018). These types of learning have suggested more rigorous assessments of high-level skills instead of content knowledge acquisition (cf. Sung et al. 2015a). Future studies may test through empirical designs to what extent the context can contribute to more successful mobile learning and problem-solving or critical thinking skills in situ. For example, MALL uses video chats, phone calls, and text messaging for authentic dialoguing in a target language (e.g., Brown 2014; Sung et al. 2015b; Tai 2012). In contrast, disconfirming studies may wish to investigate whether context-independent learning objectives, that is learning contents where the context is irrelevant to the learning, can be improved with emphasizing context or by embedding context into the learning contents.

Learning in a variety of places and times requires robust schemata. Tella (2003) and Traxler (2010) have warned that learning across various places and in small chunks of time requires that a learner combine and internalize knowledge. Moreover, learning in small episodes of time (i.e., temporal mobility; Kakihara and Sørensen 2001) may make retention problematic. Designing learning contents or encouraging learning that can tolerate disruptions and episodes of discontinuity may be very difficult to achieve (Terras and Ramsay 2012). The context-dependence of human memory and finite working memory makes learning through disruptions difficult. Disconnected pieces of information must be integrated and internalized before they can be considered knowledge (Tella 2003). However, mobile learners may be ill prepared for this.

Hill's (1999) research into information problem solving is applicable here. Mobile learners are locating more information and resources and evaluating these information and resources (Mcfarlane et al. 2008). Naïve information problem solvers, like mobile learners attempting to search for a solution to a problem, have had difficulty in identifying both what they know and do not know (Hill 1999) and feel overwhelmed (Zydney and Warner 2016). Knowledgeable learners, however, are most self-directed with a higher level of understanding for the problem domain, and they tend to use more advanced strategies for problem-solving. The more knowledgeable learners have a well-developed schema in order to integrate new or missing knowledge. So, robust mental models and schemata are most likely needed to integrate knowledge from learners with spatial, temporal, and contextual mobilities (Kakihara and Sørensen 2001).

Research is also needed to study learner characteristics in mobile learning environments. Quantitative designs may consider attempts to measure key learner characteristics that would help learners succeed in mobile learning environments, such as learner autonomy, self-direction, and self-regulation. Interventions may investigate to what extent these learner characteristics could be improved within mobile learning environments. Strong et al. (2013) reported that levels of self-directedness significantly impacted a learner's intention to use mobile computing devices to support learning. So, supporting these learner

characteristics with cognitive tools, like scaffolds, may help learners better integrate knowledge.

Using activity theory from distributed learning as a theoretical framework may also be helpful to understand how learners learn with autonomy, self-direction, and self-regulation at different times, places, across cultures and networks, and with others. Russell (2001), for example, suggests that distributed learning, like mobile learning environments, "[appears] to be most successful when people can better achieve their chosen goals by acting together than by acting alone" (p. 79). Therefore, exploring mobile learning environments that allow diverse ability levels and learning goals may accommodate complex designs where variables are not isolated (Langer et al. 2014; Van den Akker 1999).

Research designs

Extant mobile learning research has much room for improvement. Langer et al. (2014) have noted that the field of mobile learning research is still immature. Many studies have presented pilot or exploratory programs instead of well-establish interventions. Rigorous evaluation designs for mobile learning environment research are needed, and mixed methods designs seem to be most relevant and least reported (Bano et al. 2018). This aligns with Van den Akker's (1999) recommendation for research and evaluation to impact design and practice. Krull and Duart (2017) reported recent research in higher education was most commonly design-based, case study, and survey designs—with surveys as the most common data collection method. Meta-analyses by Sung et al. (2015a) and Sung et al. (2015b) point to three necessary research design improvements. Approximately one-third of studies have been within 1 week, and less than 10% have lasted longer than 6 months. Bano et al. (2018) corroborates these findings, reporting the majority of studies lasted less than 1 month. There is a need for longer intervention durations to determine both norms and authentic uses.

Highlighting the necessity for identifying the design characteristics of mobile learning environments, Sung et al. (2015a) asserted there needs to be closer alignment between mobile computing devices and learning contents. Previous studies have also focused primarily on content knowledge acquisition (e.g., Nikou and Economides 2018; Zydney and Warner 2016), and few studies have focused on more sophisticated learning goals, such as higher-level skills, problem-solving, and critical thinking (cf. Zydney and Warner 2016). Moreover, Alzahrani and Laxman (2016) found a majority of mobile learning research studies focused on learner perceptions over effects. So, future research must rigorous examine the impacts the mobile learning environment design characteristics.

More examples of constructivist pedagogies also need to be tested and explored. Research on how and to what extent models of apprenticeships (Krotov 2015), communities of practice, professional learning communities (Grant and Hsu 2014), and inquiry can and should be implemented in mobile learning environments is warranted. Finally, ethnographic studies are particularly needed with mobile learners. While there are cases describing appropriation and culture with mobile computing devices (cf. Wilken and Goggin 2012), few reports (cf. Caron and Caronia 2007; Cui and Roto 2008) of everyday experiences by mobile learners exist. How individuals move from formal learning to informal learning, from physical social networks to online social networks, or from one cultural context to another are examples of a significant lack in mobile learning research.

Conclusion

The growth of mobile devices is significant, and their uses in education, personal learning, and workplace learning continues to become impactful. Krotov (2015) asserted that mobile learning may address a number of educational problems that individuals in the millennial generation face: Because the twenty-first century is "characterized by unprecedented turbulence and change, mass-customization, rapid skill obsolescence, and 'round-the-clock' availability of products and services," mobile learning environments that are "interactive, 'anywhere, anytime', condensed, compartmentalized, and contextualized" (Krotov 2015, p. 107) may provide opportunities for individuals to live, learn, and perform in ways that have never existed and are more than technology-supported learning. If we are to provide empirical evidence and research-based recommendations for practitioners, we must be explicit in our understandings and assertions using mobile learning environments.

To achieve this precision, I have argued for the use of design characteristics of mobile learning environments over definitions of mobile learning. This follows well-established calls (Clark 1983; Herrington et al. 2010) to identify those elements within a learning environment that are unique and contribute directly to the learning. Thus, the design characteristics are a mechanism for explaining, operationalizing, implementing, and then evaluating affordances of mobile learning environments.

Criticisms that mobile learning research is misdirected and not worthy of considerable investigation (Reeves and Reeves 2015a, b) have been a clarion call. Instead of focusing on specific mobile computing devices or specific technologies, which seems to be the root of Reeves and Reeves concerns, there is a need to address the educational problems of how learners learn when moving, formally and informally, and independently and with others. Design characteristics for mobile learning environments and attributes for successful mobile learning should be defined and considered by researchers and practitioners. By explicitly identifying the unique functions and affordances of this quickly changing field in educational technology, we can meaningfully shape future educational research to focus on achieving learners' goals—not just "things."

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Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

Human and animal rights No human subjects were used in this research.

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