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Towards convergence of mobile and psychological theories of learning

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ABSTRACT

This special issue was designed to promote an integration of mobile and psychological theories of learning by inviting empirical research that draws upon both theoretical approaches to guide investigation into learning involving mobile devices. Five empirical articles illustrated how mobile devices afford resources to learners and how new channels of data afford researchers new insight into learning processes. Authors of two invited commentaries note the challenges involved in researching mobile learning, which unfolds across multiple contexts and can involve novel tools, multiple learners, and instructors and experts. These authors propose a taxonomy that can organize research that investigates interactions amongst learners, instructors, experts, and tools across one or more physical contexts, as well as a research agenda that would empirically test and refine assumptions made by mobile learning theorists. In this commentary, the editorial team proposes that mobile and psychological theories may be improved through convergence. Theories of mobile learning can be advanced by adopting practices previously employed to refine psychological theories of learning, whereas conducting research using mobile devices (and the data they provide) can further refine psychological theories of learning. We illustrate these positions with examples, and consider how instruction must be designed and how learners must be prepared in order to benefit from learning using mobile technology.

The studies in this special issue provide an opportunity to consider (1) how mobile learning technology features can inform revision of psychological theories of learning, (2) how consideration of psychological theories of learning can inform the design of mobile learning to more successfully leverage the features the platform affords, and (3) how research and theory can be enriched by greater synthesis across both fields. Across the five studies published in this special issue, research teams undertook ambitious projects that spanned the boundaries of psychological theories of learning, and embedded lines of inquiry into mobile learning to ask novel questions.

Theories that describe the way learners engage in mobile learning have begun to converge around some key features of the devices, environments where learning occurs, and the learning processes each affords. However, research programs that test these assumptions are nascent. The questions being asked are largely associative and are generally more focused on the mobile learning user's experience than on substantive cognitive or metacognitive processes, or on learning outcomes. As the body of research on mobile learning grows, investigators should begin to adopt experimental paradigms to systematically vary and observe the effects of mobile technology and contextual features, and then refine assumptions about mobile learning accordingly. In the following sections, we consider what can be learned from this set of papers that begin, understandably, with more focus on explorations of the affordances of mobile learning, and with less attention to their consequences for education. Also, we propose some potential dimensions on which psychological and mobile theories of learning might converge, then consider how mobile learning theory might be broadened to include a social cognitive perspective that accommodates educators' and learners' willingness and capacity for learning using the affordances provided by devices.

1. Mobile technologies can prompt refinements to psychological theories of learning

As mobile devices became available to the public, the major learning affordance they provided over other technologies was that they were untethered. These devices could be taken into and across various environmental contexts, including formal and informal learning spaces, where they could be used individually or could involve others in learning. In education, this portability afforded emergence of new pedagogies and research avenues, such as (1) *seamless learning*, wherein learners integrate episodes of learning with a device as they occur across contexts and varying involvement of digital media, peers, experts, and instructors (Wong & Looi, 2011) and (2) *context-aware*

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ubiquitous learning, wherein learners study real-world phenomena in situ and use mobile devices to provide immediate learning support (Crompton, 2015; Hwang, Wu, & Chen, 2007; Lonsdale, Baber, Sharples, & Arvanitis, 2004).

Mobile devices may enable learners to engage in formal learning outside of bricks-and-mortar classroom settings and to connect to media and other people when learning in informal spaces. These engagements with learning materials and other individuals are theorized to be mediated by the mobile device, which records data on such events as they occur during learning. These data can be a boon to researchers who aim to study learning as it occurs in these contexts. Further, mobile devices also have sensors that can collect novel channels of data on phenomena such as motion and location, among other variables. Such sensors can capture key contextual information on activities during learning and the physical environment where the learning occurs, as well as ways learners interact with media, their environment, and other people during learning. Researchers who study learning can access data from sensors including a microphone and multiple cameras, a gyroscope that determines direction, a magnetometer and global positioning system to provide location and compass direction, an accelerometer that provides data on speed, and even a barometer showing atmospheric pressure. Whereas some of these features may track elements of the environment that have little influence on learning processes, overall, instrumenting learners with mobile devices that collect multichannel data on learning events allows researchers to pursue research questions and obtain evidence that refines the assumptions of a psychological theory of learning they choose to investigate. As but two examples, in our introduction to this special issue we described how mobile technology can afford new windows into psychological theories of what transfers and how as well as how computer-supported collaborative learning can be better scaffolded via context-aware applications (Bernacki et al., 2020/this issue). As learning theories become more refined and instructional implications about features of a learning environment become known, mobile applications can make use of sensors in order to detect relevant environmental factors, and then those same mobile applications can prompt, scaffold, or otherwise influence the mobile learner.

1.1. Mobile devices as tools for research on engagement in context

Of the five articles chosen for inclusion in the special issue, two explicitly exemplified the utility of the mobile device as a tool for research on learning. Xie, Heddy, & Vongkulluksn (2019/this issue) capitalized upon the potential of mobile devices as uniquely powerful tools for promoting and capturing learning across multiple environments. The Mobile ESM app they deployed in their study served both as a tool to extend researchers' observation of students' engagement to new environments previously outside of their view, and as a learning intervention (i.e., the app provided students with prompts that encourage them to plan, organize, and consider their approach to learning). By leveraging the opportunity to solicit student self-reports of their motives for study in informal environments, the locations where they chose to study, and the kinds of study events that unfolded, Xie and colleagues explored features of the learning context (Lave, 1988) that influence students' behavioral and cognitive engagement in learning (Sinatra, Heddy & Lombardi, 2015). This instrumentation enabled them to examine a tantalizing subset of the dimensions of the learning context inferred by Sinatra and colleagues. With additional instrumentation to access GPS data, richer detail about the physical context can be collected. Full embrace of experience sampling methodologies can further enable researchers to probe temporal aspects of engagement via systematic and random sampling of students' affective engagement and cognitive processing during learning (Greene, 2015).

If the device can host not only the ESM app, but the digital media with which students engage during study, logs that record traces of learning events (Bernacki, 2018) can be aligned further to ESM data to understand how features of the context specific to learning objects (i.e., topic, tool, etc.) influence students' cognitive engagement and learning outcomes (Sharples, Taylor, & Valvoula, 2016). Xie et al.' (2019/this issue) initial investigation explored the role of context in the learning process and demonstrates that additional study and expanded instrumentation of mobile devices and the tasks they support can refine engagement theory in novel ways.

Lee and colleagues (2020/this issue) also investigated engagement theory and demonstrated that using multiple classes of mobile devices can afford unique insights on student engagement in learning. Their study of adolescent learners engaged in extra-curricular learning in a maker space revealed how wearable devices (e.g., wristbands that measure skin conductance) can unobtrusively measure students' behavioral engagement via physiological measures at precise moments during learning. These devices can be combined with other channels of information in multimodal studies, such as body cameras, to interpret the ways learners engage with learning objects, one another, and instructors, and the cognitive engagement that results.

1.2. Leveraging mobile devices to refine theories of self-regulated learning

The work of Xie et al. (2019) aligned well with models of self-regulated learning (SRL; Schunk & Greene, 2018), particularly in terms of the importance of prompting effective planning and strategy use to promote internalization and eventual automatic use of such processes (Zimmerman, 2013). Their work coheres with other efforts to use experience sampling to understand the dynamic, in situ nature of SRL and its relations with authentic educational outcomes (e.g., Nett, Goetz, Hall, & Frenzel, 2012). Thus, mobile technologies can obtrusively but benevolently capture and prompt SRL, as well as unobtrusively gather data on their behavioral and emotional responses to those actions that could refine and deepen theory (e.g., Academic Emotional Learning; Ben-Eliyahu, 2019).

As Harley and colleagues (2020/this issue) demonstrated, such emotional responses relate to how students make meaning from their educational experiences. Further, Harley and colleagues showed that constructs from control-value theory (Pekrun & Perry, 2014) can and do predict emotional responses in the context of mobile learning. Importantly, they provided evidence that perceptions of control and value extend beyond domains and topics and into the mobile devices themselves. Such findings expand models of emotion and emotion regulation (Harley, Pekrun, Taxer, & Gross, 2019), suggesting that the modern world prompts motivational and emotional responses across topics, domains, tools, and contexts. The dynamic interactions across these foci lead to emergent motivation, emotion, and behaviors that will require multimodal measures to capture, thus further highlighting the need for unobtrusive data collection via mobile devices. Such multimodal, unobtrusive measurements may also enable authentic investigations of controversial aspects of self-regulation and motivation, such as ego-depletion (i.e., the exhaustion of cognitive resources necessary for regulating learning; Baumeister & Vohs, 2016).

2. Psychological theories of learning can inform how mobile learning theory matures

Mobile devices are primarily designed to enable learners to connect to content, instructors, and others with whom they aim to learn. Mobile learning is rooted in theories of social and cultural processes (Crompton, 2017; Seipold & Pachler, 2011) and built on Vygotsky's (1978) theories on learning as mediated by tools. Various theories are used in mobile learning to better understand the affordances of being connected through the mobile device. Mobile learning is a multi-directional network of connections. Using the language of Latour (2005) Actor-Network Theory, mobile learning is a dispersed relay between multiple points and those relays create relationships between multiple actors in and across networks in non-linear ways. There are human actors that are the people the student interacts with, and the non-human actors, such as the devices themselves, the programs, the physical environment, and other artifacts.

In mobile learning, human actors involve students interacting with peers, instructors, experts and the world, and this can be in person, online synchronously and asynchronously. Some of the human connectivity provided through the mobile device can be driven through non-human actors, such as people interacting with programs without other human connectivity, or human-created objects such as audio, video, documents, etc. that can serve as representations of human connectivity that subsequently inform further human interaction. In some situations, learners may interact directly with non-human actors, such as when students gain information about what day it is by interacting with an automated system, have a two-way conversation with a voice assistant to seek help, or interact with artificial intelligence to produce new learning materials or pathways to learning.

Mobile learning researchers have begun to refine theory by examining how mobile devices afford learning opportunities (Wrighta & Parchomab, 2011) and how actors within networks and factors related to context shape the mobile learning process (Paledi & Alexander, 2017). These efforts might be improved by adopting lenses supplied by psychological theories of learning, which have themselves been refined through empirical testing, and which already describe analogous phenomena. For instance, the connectivity in and across actors has been explored by proponents of Activity theory (Engeström, 1987; e.g. Uden, 2007; Impedovo, 2011). Activity Theory is used to examine three elements of learning that are readily understood to exist within theories of mobile learning: the subject (i.e., an actor), the object (a digital learning resource or human resource within the network) and the instruments/tools (i.e., an affordance provided by the device itself). Activity theory provides a way of showing how students can be shaped by, and shape, their environment through their activities (Cowen & Butler, 2013). Models of mobile learning involve many components, as well as bidirectional and recursive interactions between components, which are themselves theorized to occur in nested fashion in one – and sometimes multiple – contexts. Such models are inherently complex, and require focused programs of research with considerable amounts of rich data to test the veracity of theorists' claims.

A commonly employed method of researching mobile learning is the reduction in this complexity through selection of a subset of the components of models of mobile learning and the testing of relatively straightforward assumptions about a learner's perceptions of mobile learning (e.g. Fabian & Topping, 2019/this issue). This approach will produce useful insight into the ways key components of a complex mobile learning network behave; the method also necessarily ignores the implications of other features of mobile learning as a result. In order to initiate a second wave of research that interrogates more complex assumptions of mobile learning theories, researchers who aim to fully embrace these network-oriented conceptualizations would need to adopt more ambitious research designs and develop highly instrumented data collection platforms for use with many learners. Analyzing instances of mobile learning to understand the interrelationships amongst many actors (i.e., human and non-human) might require complex modeling approaches (e.g. Hilpert & Marchand, 2018), and perhaps treatment of mobile learning as a dynamic system (Roberts, Andersen, Deal, Garet, & Shaffer, 1983, Saba & Shearer, 1994), or even a dynamical system wherein an event by one actor in a system has implications for all other actors across a network (Pavlik & Wu, 2011). Such implications may include how mobile technology and learning influence the likelihood of learner outcomes. Research presented in the special issue largely tended towards the less comprehensive and complex of these two approaches. This may derive from an editorial imposition to address research questions that derive not only from a theory of mobile learning, but also a psychological theory of learning. This imposition of integrative research spanning both mobile and psychological perspectives on learning was necessary to achieve the aims of the special issue, but also made clear that convergence will be a challenge.

Across all five studies, authors described the interconnections between the device and the learner. Xie et al. (2019) prefaced their study by citing Sharples, Arnedillo-Sánchez, Milrad, and Vovoula's (2009) assertion that learning is created collaboratively as people interact with one another, their surroundings, and tools available to them. Fabian and Topping (2019/this issue) used the Micro Meso and Macro (M3) evaluation framework (Vavoula & Sharples, 2009) as a model to examine usability, educational and organizational impact, and their interrelationships. Often, the studies included mobile learning integration considerations, such as focusing on the role of the learner as the driver of learning, and to some degree, the features of the environment that allow the learner to engage with content.

To a varying and far lesser degree, the authors made references to the theories of learning that guided their application design. This is partially an artifact of the current status of the mobile applications that afford this research: most apps are developed as part of research projects at the bleeding edge of theory and practice. The functionality of the apps are often narrowed to fit the scope of the research. These apps are also in an early stage of their development, and have not reached a level of maturity required to make them publicly available. Whereas considerable attention is paid to the affective experience of the learner when engaged with the device (e.g., emotions in Harley et al., 2019b/this issue; satisfaction and usability in Fabian & Topping, 2019/this issue), little description is provided regarding the explicit cognitive processes that students engage in when interacting with the content and tools provided by the mobile apps. Xie et al. (2019) captured self-reports of the depth of students' cognitive processes when studying, albeit with materials not hosted on a mobile technology. Lee and colleagues (2020/ this issue) captured a signal of the presence of heightened cognitive engagement when engaging in activities observed via body camera during making. On the other hand, Fabian and Topping (2019/this issue), Epp and Phirangee (2019/this issue), and Harley et al. (2019b/this issue) did not utilize online measures that could capture student engagement with learning objects. Instead, their use of observational approaches left unexamined the explicit cognitions and metacognitions of the learners when engaged with the tools and content that mobile devices can uniquely provide. As a result, additional studies will be needed in order to refine this connection between psychological and mobile learning theories. As Mayer (2020/this issue) illustrated, behavioral engagement does not necessarily indicate cognitive engagement; researchers who advocate for the promise of mobile technology for learning must demonstrate that learning behaviors over episodes that span multiple contexts – a phenomenon that derives from the unique affordance of the mobile device – actually lead to positive cognitive, motivational, emotional, and learning outcomes.

A more principled relationship between educational theorists and mobile developers could improve the convergence of psychological theories of learning and mobile learning theory if lessons derived from the science of learning informed the design choices made by developers, and these platforms could be instrumented to capture evidence of student interactivity with digital media indicative of such processes. The cognitive processes that students engage in could further be informed by a cognitive task analysis (Koedinger & McLaughlin, 2016) of the learning task itself. This process could be similarly extended to the consideration of connectivity with peers by examining the psychological literature on socially shared regulation of learning (Hadwin, Järvelä, & Miller, 2018) to understand key environmental requirements that make collaboration possible (e.g., individuals having own devices, per result of Fabian & Topping, 2019/this issue), and how to support collaborative processes to ensure productive cognitive engagement and metacognitive regulation of the individual and the group.

A third wave of theoretical supervision of the learning process is needed to guide connectivity with instructors. Ample literature on help-seeking in adaptive learning technologies and in classroom environments should be leveraged to inform the features necessary to alert teachers to student needs. This would enable instructors to support learners as they drive their own engagement in mobile learning. Further, the help-seeking literature can inform the classroom instruction that follows when learners reconvene with instructors, who can subsequently design lessons based on data describing learners' engagement with mobile platforms, reflecting common areas of success and difficulty developed (e.g. Holstein, McLaren, & Aleven, 2018).

3. Mobile learners need to be prepared to leverage the tools available to them

Mobile learning provides students with unique opportunities to engage in effective cognitive strategies across formal and informal contexts, but students will need to learn how to deploy these strategies in order to benefit from such an opportunity. Evidence from educational psychology research suggests that the majority of students are hesitant to engage in learning contexts that are "flipped" to ensure a learner-driven experience (Deslauriers, McCarty, Miller, Callaghan, & Kestin, 2019). In addition, learners further insulate this hesitancy through a cognitive bias that convinces them that they learn more when they engage passively inside the classroom and via mobile technology. These findings make clear that successful development of mobile learning will require collaboration between developers and educational psychologists to promote engaging *design* and effective methods of *integration* of mobile technologies into educational settings. Those who engage in such collaborations might then focus on key indices such as performance outcomes, targeted learning processes, and desired affective responses to evaluate the implications of their design choices. Once students are engaged in mobile learning, applications will need to develop students' ability to use the tools they provide, scaffold this use, and potentially reprompt effective use after training and scaffolding have been faded.

Students' tendency to avoid engaging learning contexts like those afforded by mobile devices is likely to diminish the richness of their interactions with the tools mobile devices are uniquely able to provide. Many of the research questions proposed and answered in this special issue address these concerns about the user experience, their motivation, and their implications for engagement, learning, and performance. Systematic research that tests how design choices can elicit student engagement will be necessary to ensure that students are willing to leverage the affordances that mobile platforms provide.

Once effective mobile devices are designed, classroom and field studies will be needed to examine *integration*. That is, studies must be undertaken to answer the question, "how do different approaches to the adoption and implementation of mobile devices affect students' engagement with and during learning?" The findings from this work will enable instructors to use implementation methods that can best leverage mobile devices to enrich learning experiences in ways that cannot be achieved without such technology (Puentedura, 2009). Likewise, feedback to students on their emotional responses and how they interpreted them (e.g., Harley et al., 2019b/this issue) may help students better calibrate their expectations regarding the affordances of active learning and mobile technologies.

3.1. Designing implementations to promote engagement and learning

Technology integration frameworks, such as the Technological, Pedagogical, and Content Knowledge (TPACK) framework and Substitution, Augmentation, Modification, and Redefinition (SAMR) frameworks were highlighted in the introduction as a lens for researchers and practitioners to design learning experiences that promote learning. Fabian and Topping (2019/this issue) recognized the importance of integrating the use of mobile devices in meaningful ways and to accomplish tasks that cannot be conducted without technology.

In Fabian and Topping's (2019/this issue) study, they conducted observations to determine the type of pedagogies instructors employed, and used the SAMR framework to categorize these activities. Epp and Phirangee (2019/this issue) documented how students chose to integrate their own use of a mobile assisted language learning (MALL) application. Their largely descriptive findings provide an early glimpse into the kinds of metrics that can be observed that characterize ways learners choose to engage in mobile learning. When collected across many users and connected with measures of learning outcomes (i.e., speed, efficiency, and amount of language learning progress), these data can inform recommendations to learners who seek to use mobile applications and their tools.

3.2. Developing student capacity to skillfully engage with mobile tools

In addition to acknowledging their hesitance to engage in active learning when given the choice, students also acknowledge that they are not confident they possess the skills necessary to learn during complex tasks (Perez, Cromley & Kaplan, 2014). Research examining the learning strategies students use further demonstrates that the typical students' academic toolkit is rather limited, and that the strategies students do choose to employ are seldom the ideal methods for developing the depth of understanding required by their course's learning objectives (Karpicke, Butler, & Roediger, 2009).

If students are to leverage the affordances of mobile technologies and benefit from a contextualized, adaptive, and interconnected learning environment, students will need to be trained to successfully deploy the learning strategies such tools are meant to support. To illustrate the kinds of skills students may need to possess to benefit from the opportunity to learn using a mobile device, we consider each of the papers in the special issue in terms of the kinds of cognitive and metacognitive skills that might be required to successfully engage in reasoning with the content presented using the mobile tools and types of connectivity afforded.

3.2.1. Cognitive strategies afforded by mobile technology

Connectivity within informal spaces affords learners the chance to scan their environment, identify features that might help them learn, and consider those features' relevance to their learning goals. For example, students may need to engage in elaborative interrogation to complete some tasks (e.g., learning historical facts and concepts via "mediating artifacts" in Harley et al., 2019a/this issue), whereas for other mobile-learning afforded tasks they may have to engage in visual search and feature abstraction (e.g. identifying geometric properties, in Fabian & Topping 2019/this issue). Feature abstraction is key to developing schema and transferring learning to new contexts but is notoriously difficult to achieve (Gick & Holyoak, 1983; Melby-Lervåg, Redick, & Hulme, 2016). Because mobile devices allow learning to occur seamlessly across contexts, they may be able to diminish the metaphorical distance across which learners must transfer knowledge, such as when engaging in feature abstraction. Learners may be more apt to use devices, and the cognitive strategies they afford, in formal learning settings, which in turn may make them more likely to reuse those cognitive strategies in informal settings. Students can reaccess resources in order to apply knowledge they have acquired in the past to novel scenarios in informal settings. They may also be more apt to reuse a strategy that a tool affords when that tool remains available via a device that is mobile. To further enhance the likelihood of transfer, mobile learning developers should consider research on methods to increase students' tendency to search for information, and to engage in critical questioning (Rouet, Britt, & Durik, 2017). Without developing these tendencies, students are unlikely to make extensive use of mobile devices' ability to deliver content in informal settings (i.e., as seen in Epp and Phirangee, 2019/this issue, and foreshadowed in Harley et al., 2019a/this issue).

Epp and Phirangee (2019/this issue) embraced this idea of learning anytime, anywhere by designing a platform where language learning can happen in the margins of one's day. In order to leverage the device, students needed to be motivated to engage with it, and to do so effectively by using an expedient cognitive strategy (i.e., retrieval practice) that is afforded by the device and aligns to the language learning task. Demmans Epp and colleagues' thoughtful design produced a mobile learning application that enabled learners to recapture time for a learning task that is vital, but is often pushed into the co-curricular spaces. Fabian and Topping (2019/this issue) leveraged the mobility and interactivity of the mobile device to afford students opportunities to engage in an activity analogous to generative drawing (Leutner & Schmeck, 2014) as they took pictures of shapes that reflect important geometric phenomena. This cognitive strategy is known to be effective for developing conceptual understanding of complex knowledge, and might further enhance student learning gains when multimedia learning principles are taught to students as they take pictures of objects in their daily life, and annotate them to illustrate their features via drawing and labels (i.e., multimedia, signaling, and spatial contiguity principles; Mayer, 2014). If these affordances of mobile learning are found to enhance students' ability to recognize geometric features of objects encountered in daily life, this would provide further evidence that mobile learning can promote schema development and the transfer of it to future scenarios, due to the seamless availability of mobile tools and the observation and reasoning they may engender. In order for mobile learning to have effects on students' learning outcomes, students must engage effectively in strategies such as retrieval practice and generative drawing. To derive their anticipated benefits for learning, mobile applications must introduce, develop, and monitor students skillful engagement in these powerful strategies.

3.2.2. Metacognitive processes that can be supported by mobile technologies

The near-ubiquitous nature of mobile devices in the modern world makes the distribution and use of mobile learning technologies much more feasible; people can download apps and access information literally wherever and whenever they need them. This capacity exists in developed nations where mobile devices are largely accessible across socioeconomic brackets, as well as in the developing world where organizations such as UNESCO – the education division of the United Nations – continue to support policies that broaden access to mobile devices (i.e., with aims to empower women and girls, continue the learning of refugees, and provide learning opportunities for those in Sub-Sahara Africa; UNESCO, 2018). Indeed, apps such as the one proposed by Harley and colleagues (2020/this issue) could be advertised in the airport or on the streets of Edmonton, sparking situational interest among people who would otherwise not think to view their trip to the city as an opportunity for learning. That said, the use of personal mobile devices as vehicles for the delivery of mobile learning tools also brings the potential for distraction (Feng, Wong, Wong, & Hossain, 2019). Academic goal pursuit on a mobile device more commonly used for entertainment purposes may require unique types or amounts of self-regulation to stay on task and resist the entertainment options available on the device (Baumeister & Vohs, 2016). Therefore, the developers of mobile learning apps and devices may need to investigate how to teach people to monitor and control their volition (i.e., the enactment and maintenance of goals in the presence of distractors or competing goals; Oettingen & Gollwitzer, 2015). Research on volition interventions in education are scarce (cf. Hoch, Scheiter, & Schüler, 2017), but in the larger psychological literature there are promising examples of the efficacy for Mental Contrasting with Implementation Intention interventions, where participants are trained to identify desired goals, the obstacles that might prevent attaining them, and then how to automate strategies to circumvent those obstacles should they occur (Oettingen, Schrage, & Gollwitzer, 2015). In the case of mobile learning, such an intervention might cue learners to metacognitively monitor the temptation to check social media rather than continue using the learning app and then automate a control strategy to pause all mobile device use for five minutes until the temptation passes.

Mobile learning devices thus require students to metacognitively self-regulate. They also have the capacity to develop students' ability to regulate their own learning, as well as their collaborative learning with other learners. Xie et al. (2019) demonstrated that pre-service teachers could successfully use features of a mobile app to plan, organize, and monitor their learning. These students demonstrated these skills by using – and may have been assisted by – dashboards that visualized their own progress towards goals. If apps can assist mobile learners by encouraging them to self-regulate and providing support that helps them to do so effectively, the mobile app has the potential to improve individuals' learning with the device, and potentially help learners develop skills that can be deployed in non-mobile settings.

The opportunity to connect with other learners is a central feature of mobile learning that is explicitly afforded by mobile devices. Though no paper in this special issue investigated this feature, theories that outline successful principles of socially-shared regulation of learning have begun to emerge (Hadwin et al., 2018). Research that tests these theories confirms that students are more successful in regulating their collaboration when it is scaffolded (Järvelä et al., 2016). As learners connect and learn together, developers of mobile technologies may wish to design scaffolds to facilitate effective regulation through prompts and other features, and to help support students as they learn to regulate their collective goals, and one another (Lobczowski, Lyons, Greene, & McLaughlin, 2019).

In addition to connecting with peers, mobile learning affords connectivity with instructors and experts. This form of connectivity enables instructors to improve the timeliness and precision of feedback on learning. For this to be achieved, teachers need to be available to provide feedback, and traces of students' learning process need to be made visible in ways teachers can conveniently appraise and interpret. Absent in all but one of these exemplars, but prominent in the field of learning analytics (e.g., Rienties et al., 2019) is a consideration of a dashboard to inform learning. Dashboards are essential metacognitive tools that enable learners and instructors to monitor the amount, focus, and success of cognitive strategies, and can inform how students persist in or adapt their learning. To create these dashboards, mobile developers should partner with instructional designers, teachers, and users to consider how the learning task is meant to unfold (i.e., conduct a cognitive task analysis) to determine the key events known to influence learning outcomes including the micro level events that learners demonstrate (i.e., per M3 framework [Vavoula & Sharples, 2009] in Fabian & Topping, 2019/this issue and microlearning theory in Epp & Phirangee, 2019/this issue) and their association with targeted learning goals.

Dashboards will need to be designed so that instructors and learners can monitor the micro-level progress being made during specific learning tasks, as well as progress toward macro-level outcomes including concept learning and the efficiency with which these outcomes are achieved (Koedinger, Corbett, & Perfetti, 2012). Much could be learned from considering Open Learner Models in the intelligent tutoring system literature, wherein researchers investigate how such feedback informs individual learners (Long & Aleven, 2011) and how classroom-wide dashboards afford connectivity with and efficient scaffolding by instructors (Holstein, McLaren, & Aleven, 2017). Across user groups, the effectiveness of dashboards can be further heightened by aligning to principles of multimedia learning (c.f., Mayer, 2014) to ensure they are easy to interpret for learners whose self-monitoring skills are limited. Lessons learned from these literatures can help developers present learners with data on their progress and achievement in ways that inform their monitoring decisions, which guide future learning. Lessons about dashboards that aggregate student data can connect individual students' use of mobile devices with informed, adaptive instruction by teachers, who can determine when to support individuals, groups, or whole classrooms to improve learning of key concepts and the metacognitive knowledge and skills necessary to seamlessly continue such learning across formal and informal contexts.

4. Conclusion

Mobile learning is a developing concept in education that is informed by a developing base of theory, which, in turn, is becoming more systematic in its description of the affordances it provides to learners. Additional research guided by systematic lines of inquiry and informed by ideas from psychological theories of learning and human-computer interaction can inform its refinement. The use of mobile devices can provide methods of inquiry that provide reciprocal benefits to the refinement of psychological theories of learning by affording new measurement opportunities, such as the sensing capabilities of mobile devices, to test assumptions about context, among other assumptions. Educators and learners are also developing in their willingness and ability to skillfully use mobile learning technologies; their awareness of how one employs skills within these emergent technological platforms will need to be trained and scaffolded, and learners will need to be encouraged to use tools, rather than acquiesce to more passive methods of learning. Development of devices and applications that afford mobile learning opportunities that yield observable improvements in learning outcomes is likely to be most successful when design of learning activities and applications are guided by a theory of learning and assumptions about the ways students engage in learning seamlessly across environments and when connected to media, peers, instructors and experts. Such theory must be rigorously investigated, tested, and refined. Mobile learning theorists stand to benefit from adopting methods that have been used to refine psychological theories of learning as they systematically research mobile learning and examine this complex phenomenon during authentic formal and informal learning.

The convergence of mobile learning theory with psychological theories of learning will require the adoption of a person-and-tool-in-environment consideration that bridges a situated, learner-centered perspective, as well as a design and integration-centered perspective to evaluate how a learner is equipped, how a tool is equipped, how the activities are developed to leverage the tools, and how the combination of those affordances are used to produce a learning opportunity that was not previously available. Achieving this level of understanding will require that mobile learning theorists continue to refine assumptions about what mobile learning affords, how these tools are integrated into learning, and what kinds of skills educators and students will need to be able to effectively employ those affordances. A critical-analytic perspective on the integration of psychological and mobile theories of learning, as well as the tools they afford, will be necessary to bring to full fruition the many promising directions for future research and education.

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