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Understanding mobile learning from the perspective of self-regulated learning

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Abstract Cognizant of the research gap in the theorization of mobile learning, this paper conceptually explores how the theories and methodology of self-regulated learning (SRL), an active area in contemporary educational psychology, are inherently suited to address the issues originating from the defining characteristics of mobile learning: enabling student-centred, personal, and ubiquitous learning. These characteristics provide some of the conditions for learners to learn anywhere and anytime, and thus, entail learners to be motivated and to be able to self-regulate their own learning. We propose an analytic SRL model of mobile learning as a conceptual framework for understanding mobile learning, in which the notion of self-regulation as agency is at the core. The rationale behind this model is built on our recognition of the challenges in the current conceptualization of the mechanisms and processes of mobile learning, and the inherent relationship between mobile learning and SRL. We draw on work in a 3-year research project in developing and implementing a mobile learning environment in elementary science classes in Singapore to illustrate the application of SRL theories and methodology to understand and analyse mobile learning.

Keywords elementary science, mobile learning, self-regulated learning (SRL).

Introduction

Personal, portable, and wirelessly networked technologies are becoming prevalent in the lives of learners. This leads us into a new phase in the evolution of technology-enhanced learning, one that forges new mobile learning spaces and the continuity of the learning experiences across different scenarios or contexts (Clough *et al*. 2008; Frohberg *et al*. 2009; Looi *et al*. 2010, 2011; Zhang *et al*. 2010).

The purpose of this paper was to theoretically explore how the theories and methodology of self-regulated learning (SRL), an active area in contemporary educational psychology, can provide a lens to address issues originating from the defining characteristics of mobile learning. An analytic SRL model of mobile learning is used as a conceptual framework for understanding the nature of mobile learning. The conceptual link between mobile learning and SRL will be established through their connections with the notion of lifelong learning. The mechanism and processes of mobile learning are understood and analysed from the perspective of SRL in an authentic mobile learning system.

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Conceptual link between mobile learning and self-regulated learning

Ubiquity – defining feature of mobile learning

The essential difference between mobile learning and other types of learning activities lies in the assumption that learners may be continually in motion (Sharples *et al*. 2005, 2007). This significant characteristic of ubiquity enables learners to learn the right thing at the right time at the right place (Peng *et al*. 2009). In their words, ubiquity 'refers not to the idea of "anytime, anywhere" but to "widespread", "just-in-time", and "when-needed" computing power for learners' (p. 175). However, this idea results in a series of follow-up questions. For example, who assumes the responsibility of determining what (right things), when (right time), where (right place), and how to learn (right strategies): instructional designers, teachers, or students themselves or all of them in different contexts? How do educators equip students with the necessary knowledge and skills that enable them to not only make such judgements but also to appropriately control their learning based on such judgements?

A relevant issue is that effective mobile learning is assumed to be dependent not only on learners' capabilities in rightfully determining what, when, where, and how to learn but also on their willingness to behaviourally and cognitively engage in learning whenever/wherever they themselves realize it is needed. This suggests that a student-centred mobile curriculum involves more than technological or pedagogical considerations, and learner characteristics such as motivation and abilities in monitoring and controlling one's learning in different settings need also to be considered.

In this sense, mobile learning environments (MLEs) presumably provide a means by which students can exercise agency to control their own behaviour and cognition. What theoretical perspectives are needed to design, analyse, and evaluate mobile learning? This paper will provide a conceptual framework for these questions.

Challenges in the current theorization of mobile learning

A challenging question asked by Vogel *et al*. (2009) is: do using mobile technologies really lead to learning? They likened it to the old adage that leading a horse to water does not mean it will then drink from the water. They found that providing technological supports and mobile devices does not necessarily ensure effective learning. If so, what would be the external and internal factors underlying the appropriation of personal, portable, wireless technologies for impactful and effective teaching and learning? Essentially, this is a classic and fundamental issue in learning design: what are the factors that improve, enhance, impinge, or hinder academic achievement?

Vogel *et al*. (2009) claimed that the effectiveness of using mobile technologies on meaningful learning faces constraints in three dimensions: the human dimensions (students and instructors), the design dimension (content, technologies), and the institutional dimension (schools). Wali *et al*. (2008) pointed out that in many existing studies, the focus has been on the dimensions of design and institution have been focused, thus placing greater emphasis on the technology and less on learning and the experiences of learners. It is the learner that is mobile rather than the technology (Sharples *et al*. 2005, 2007). Vogel *et al*. (2009) claimed that besides the technological, pedagogical, and institutional constraints, student's appreciation of deep learning and skills in time management, as well as motivation, play significant roles in engaging and sustaining students to apply mobile devices to meaningful learning.

Although mobile learning is becoming popular in the field of educational technology, there is under-theorization about the nature, process, and outcome of mobile learning (Sharples *et al*. 2005, 2007; Wali *et al*. 2008), and the kinds of characteristics of mobile learners that can help nurture lifelong learning dispositions. Many existing studies (Waycott *et al*. 2005; Zurita & Nussbaum 2007; Wali *et al*. 2008; Liaw *et al*. 2010) grounded and conceptualized the application of mobile technologies to learning in the framework of activity theory.

From the perspective of activity theory, learning is oriented by goals, i.e. goal-directed. In the cognitive view of motivation, a learning goal set by a learner represents her motivation (Schunk *et al*. 2008), one of her learner characteristics underlying learning processes. From the semiotic perspective of mobile learning under Sharples *et al*.'s (2005, 2007) framework, mobile learning is directed by learners' goals. Thus, learners are supposed to be the agents of learning rather than the tools (e.g. mobile technologies and devices), namely the control of learning is based on learners' self-regularity or autonomy (Liaw *et al*. 2010).

Although existing theories in mobile learning (e.g. activity theory and Sharples' argument) attach adequate importance to the role of the learner in effective mobile learning, further research is still needed to unpack the roles of learner characteristics such as student's motivation in understanding and analysing the mechanism and processes of mobile learning. The central question is what learning theories are needed to advance mobile learning theories and research so that our knowledge about the nature and process of, as well as underlying factors in, mobile learning can be more theoretically validated and empirically supported.

Waycott *et al*. (2005) examined the inherent relationship between the notion of lifelong learning and mobile learning, and pointed out that lifelong learning is in nature mobile with respect to place and it involves learning in transitions across different areas of life (schools vs. museum or home) and time. Equipping students with knowledge and skills for lifelong learning is regarded as a major goal of contemporary education in which mobile learning is subsumed. These skills are viewed as not only crucial for managing one's own learning during formal school education but also for keeping one's knowledge abreast after leaving school (Boekaerts & Corno 2005). Among the factors that are important for lifelong learning, *motivation* and *self-regulation* are the two central determinants (Boekaerts 1997; Schober *et al*. 2007).

Therefore, our argument is that the ubiquity of mobile learning intrinsically calls for the theories of SRL (Zimmerman & Schunk 2001; Boekaerts & Corno 2005; Schunk & Zimmerman, 2008). Knowledge and skills of SRL can be seen as a precursor to mobile learning, as well as one of the desired outcomes of mobile learning given that the design and implementation of mobile learning systems fit the principles of SRL. Handheld computers should be used as cognitive tools (Chen *et al*. 2008) and metacognitive tools for learners.

Self-regulated learning

Human behaviour is conceived as the product of an internal guidance system that inherently is organized; thus, the mechanism underlying human behaviour is a system of self-regulation (Carver & Scheier 1998). The construct of SRL that is rooted in Bandura's social cognitive theory (i.e. reciprocal determinism) (Bandura 1986; Zimmerman & Schunk 2001) claims that personal cognition (e.g. cognition, affect, and academic achievement) is reciprocally determined by behavioural (e.g. logging onto a computer-based learning system) and environmental (e.g. instructional design, teacher's feedback) factors. In this theory, human beings are viewed as proactive, self-organizing, and self-regulating rather than reactive organisms solely either shaped by external environmental influences or reflexively stimulated by genetic inner impulses (Bandura 2001; Martin 2004). This implies that the effectiveness of any learning environment on learners' behavioural engagement in learning is mediated by learner characteristics (personal factors) such as prior knowledge, goals, and self-perception of the task. When designing a MLE, designers should be concerned not only with pedagogical and technological issues but also the learners' personal factors and behavioural patterns.

Various SRL theories share three basic assumptions (Zimmerman & Schunk 2001), namely that self-regulated learners are able to (a) personally improve their ability to learn through selective use of metacognitive and motivational strategies; (b) proactively select, organize, and even create advantageous learning environments; and (c) play a significant role in choosing the form and amount of instruction they need. These assumptions about the nature of SRL essentially converge at a fundamental meta-theoretical element intrinsic in all SRL models – human agency. Self-regulating learners are agents who are self-proactive and self-organizing (Bandura 2001; Martin 2004). Taken together, self-regulating learners actively participate in their learning processes metacognitively as well as motivationally and behaviourally (Zimmerman & Schunk 2001).

The notion of agency assumes that individuals possess self-beliefs that enable them to control their thoughts, feelings, and actions (Bandura 2001). Furthermore, human agency refers to an emergent capability of individual humans to make choices (i.e. setting goals) and to act on these choices constituted primarily through interaction between brain activities and sociocultural contexts (Bandura 2001; Martin 2004). Agency is both determined by and determines the environment, essentially eliciting two key components of SRL: *motivation* and *metacognition*.

Metacognition refers to the study of what people know about their cognitive and memory processes, and how they put the metacognitive knowledge to use in regulating their information processing and behaviour (Koriat 2007). Metacognition has been referred to as cognition of cognition, knowledge about one's cognitive process, as well as skills of regulation of cognition (Nelson 1999).

Motivation is regarded as a multi-faceted construct. From a cognitive perspective, 'motivation is the process whereby goal-directed activity is instigated and sustained' (Schunk *et al*. 2008, p. 4). Research has shown that the variance of student's performance and achievement in mobile learning can be accounted for by the degree to which individual students are motivated intrinsically to ubiquitously engage in mobile learning activities (Vogel *et al*. 2009).

Autonomy is reviewed as a basic innate psychological motive of human beings (Ryan & Deci 2000). The need for autonomy refers to a sense of controlling over or self-determining one's behaviour. Intrinsically motivated people engage in an activity because they find it innately interesting and enjoyable. In contrast, extrinsic motivation leads people to engage in an activity as a means to attain some separate outcomes such as a reward or avoidance of punishment. Intrinsic motivation corresponds to the proactive and growth-oriented nature of human beings (Ryan & Deci 2000).

Understanding mobile learning from the lens of self-regulated learning

This section begins with an overview of the background of our 3-year research project in designing and implementing a MLE for elementary science classes in Singapore. The nature and processes of mobile learning will be studied from both SRL theoretical and methodological perspectives.

Background of our research on mobilized lessons

The role of SRL in theorizing mobile learning can be epitomized from two aspects. One is concerned with the basic considerations in designing MLEs in which self-regulatory skills can be nurtured naturally. The other refers to how SRL provides a theoretical framework for understanding and analysing students' self-directedness in the processes of mobile learning. The present study mainly manifests the latter.

In the research, a Primary (Grade) 3 and 4 science curriculum was transformed for delivery by means of mobile technologies, and a teacher enacted the lessons over the 2009 and 2010 academic year in a primary class in Singapore (Zhang *et al*. 2010). The students had a total of more than 40 weeks of the mobilized lessons in science, which were co-designed by teachers and researchers. As defined by Norris and Soloway (2008), a 'mobilized lesson' refers to a lesson starting with a conventional paper-based lesson design and then being transformed to a mobile device-based instructional design by tapping into the affordance of mobile technologies for supporting inquiry learning in and outside the class.

The mobile device the students used was HTC smartphone (Taoyuan, Taiwan) in which the Microsoft Windows Mobile 6 operating system was installed along with a calculator, a calendar, mobile web Internet access, MS Windows Mobile Word™, Excel™, and PowerPoint™, which provided the affordance of basic Math computation, self-monitoring mechanism, digital production, data collection, data storage and analysis, and presentation.

The GoKnow™ MLE (Dallas, Texas) that runs on Microsoft Windows Mobile operating system was selected because it supports collaborative inquiry. The GoKnow™ MLE enables teachers to create differentiated lessons easily via its online learning management system, GoManage. MLE is an environment in which students engage in the specific learning activities to create various artefacts. It includes software tools such as

- KWL (what do I already Know? what do I Want to know? what have I Learnt?) (Ogle 1986) to allow students to learn through a goal-oriented process (see Fig 1);
- Stopwatch that supports timing of events;
- Sketchy™ as an animation/drawing tool; and
- Picomap™ that allows students to create, share, and explore concept maps.

For educators and teachers, two strategies are generally used to nurture students' self-regulatory capabilities (Kistner *et al*. 2010). One is to have teachers directly teach students SRL skills in classrooms. The other is the indirect approach of designing a learning environment in which students are offered authentic practices to actively experience the key processes of SRL (i.e. cognitive, metacognitive, and motivational) guided by teachers or cognitive and metacognitive tools built in computer-based learning systems (Azevedo 2005). Adopting the second approach, the mobilized

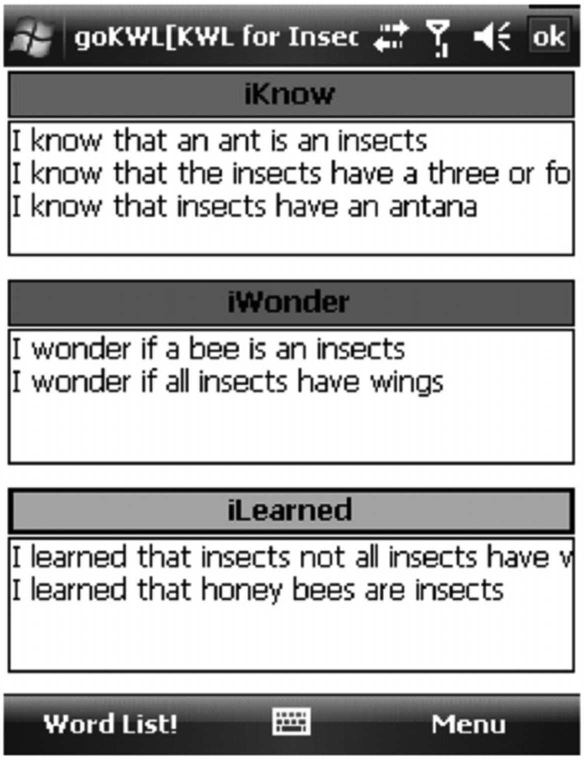

Fig 1 An example of KWL (what do I already Know? what do I Want to know? what have I Learnt) in GoKnow™.

lessons that were co-designed by researchers with classroom teachers were intended to provide a learning environment that activated and facilitated individuals' SRL capabilities.

Understanding mobile learning processes within a SRL model

There are two aspects from the perspective of SRL to determine whether students can choose the right things to learn at the right time and right place in a mobilized curriculum. First, students must be motivated to engage in inquiry cognitive activities in order to make mobile learning effective. Second, students must acquire necessary domain knowledge, as well as metacognitive knowledge and regulatory skills, so that they are able to monitor, control, and regulate their own cognitive and motivational processes in mobile learning.

Effective mobilized lessons are expected to support the students' need for autonomy, an innate psychological needs (Ryan & Deci 2000), by offering them some choices in each sub-process of SRL. This sense of autonomy in learning was facilitated by offering each student a smartphone computer as a personal learning tool during the 2-year duration of their experimental use. They were not only responsible for the basic maintenance of the phone (e.g. charging the battery), but, more importantly, they owned the cognitive and metacognitive outputs (e.g. KWL, concept maps, and animations) they produced in the phone by means of the built-in software tools (e.g. Sketchy™). A perception of personal autonomy in owning and controlling learning tools (physical and intellectual) plays a prominent role in motivating students to engage in mobile learning activities. Activity theory attaches overwhelming importance to tools as the pursuance of learning goals by learners is mediated through the use of a tool. In the light of SRL, providing each student with the ownership of learning tools sets a necessary condition with which intrinsic motivation might be self-initiated.

We describe one episode that demonstrates how mobile devices can support the students to actively engage in a learning activity whenever they are motivated to do that. In one of the lessons on 'Light', the teacher was demonstrating how the amount of light could affect the operation of a solar toy frog and mini solar windmill. The experiment could not be completed due to bad weather and the demonstration was curtailed. Isabel (a student) approached the teacher two days later and sought permission to borrow the gadgets to run the experiment on her own accord. Together with another classmate, Isabel conducted the experiment at the compound near the canteen. She keenly observed what happened and drew the conclusion that the solar frog required more solar energy to operate. In the midst of conducting the experiment, more classmates gathered round them and some took out their smartphones to record the whole experiment. In that case, the mobile devices were used by the students as a portable cognitive tool where and when they were motivated to engage in a learning activity.

Winne's (2001, 2011) phase model of SRL is used to illustrate how the design of MLE facilitates SRL and how SRL can help understand the mechanism and processes of mobile learning. His model postulates that SRL unfolds over four weakly sequenced and recursive phases: *defining the task*, *setting learning goals and plans*, *enacting*, and *adapting*. Theoretically, the first three phases are necessary and the fourth phase is optional, depending on whether the entire approach to

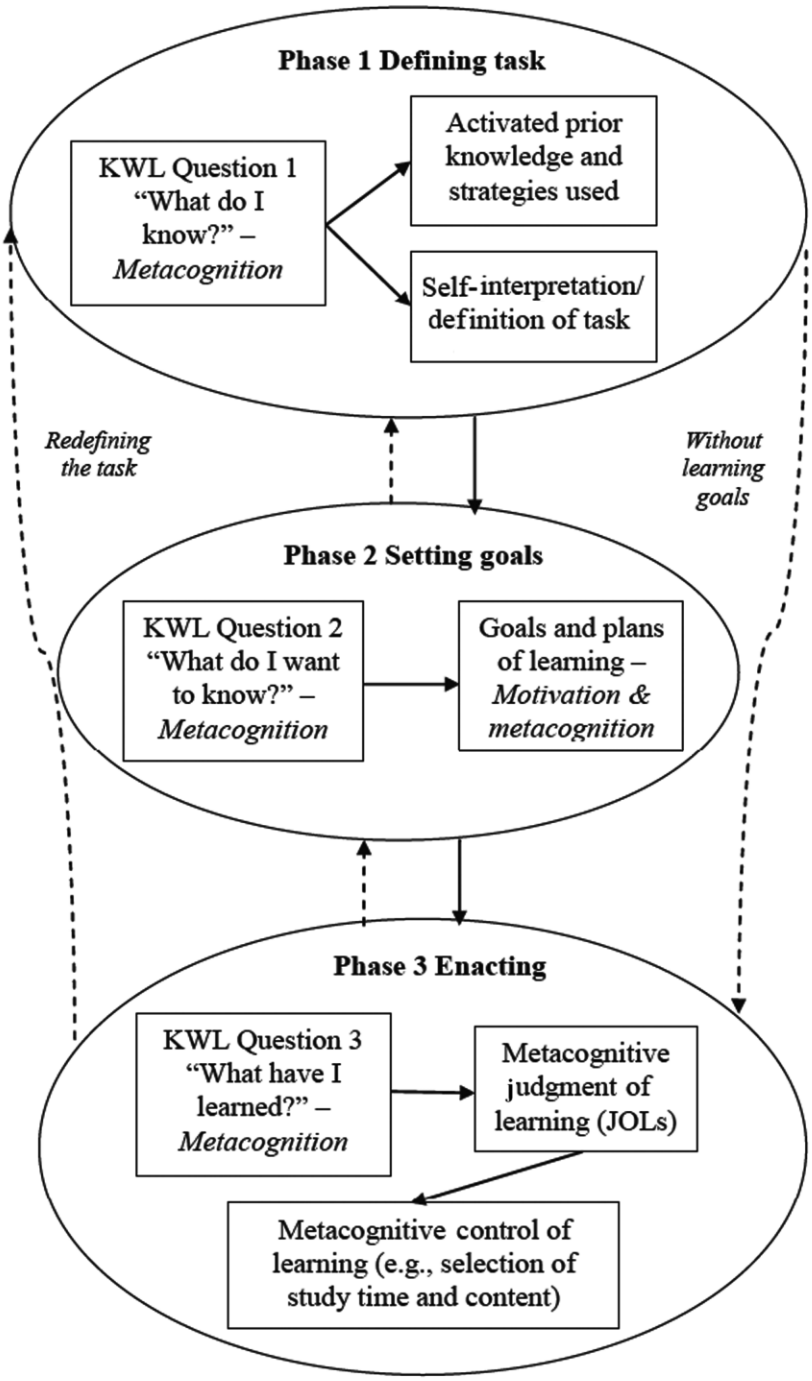

Fig 2 Roles of KWL (what do I already Know? what do I Want to know? what have I Learnt) in the three necessary phases of Winne's model of self-regulated learning (Winne 2001).

work is to be evaluated at the end of a task (Winne 2011).

The following analysis will be focused on how the built-in KWL questions scaffold the students to go through the three necessary phases (Fig 2). In the figure, the recursive feature of this model is denoted by the dotted arrows, indicating the possible impacts of psychological states at any subsequent phases on those at any previous phases. For example, a learner may make some adjustments to the learning goals he or she sets in phase 2 or may reconstruct his/her perception of the task he or she generated in phase 1 once he or she actually engages with learning cognitively and metacognitively in phase 3.

The mobilized lessons co-designed with the teachers usually began with a collaborative (e.g. cooperative game) or individual activity (e.g. browsing the instructional objectives presented on the smartphone) from which the students could get some initial knowledge about the background and topic of the lesson, as well as a few challenging questions addressing the key concepts (e.g. magnet) to learn. This corresponds to phase 1 in a SRL process, which may yield two mental outputs: *task conditions* and *cognitive conditions* in each individual's mind (Winne 2001). The former is external, situational information about the task such as the goals set by the teacher, the format of the task, the choices they have, and the time available. The latter involves activation of prior knowledge and experiences stored in the long-term memory.

Metacognitive monitoring and metacognitive control are the pivots with which a SRL turns (Winne 2001), implying metacognitive operation is presumably ubiquitous throughout the process of SRL, as illustrated in Fig 2. In phase 1 of SRL, by using KWL (I Know, I Want to know, and I Learn) and answering the teacher's triggering questions, the students were actually metacognitively monitoring the degree with which they had understood the lesson. In this sense, the KWL built in the mobile learning system functions as a cognitive tool by activating learners' prior domain knowledge of the task, as well as a metacognitive tool by monitoring the availability of the existing knowledge and resources in completing the task.

The direct output of phase 1 is each individual's definition of the task (mental representation of the task, as illustrated in Fig 2) in which the profile of the designed task would be likely reconstructed and varied across the students. Thus, each of them perceives the task differently. For example, based on their own activated prior knowledge and experiences in the same or similar situations, student A may feel the task is easy to complete, while student B may feel it is not. Therefore, Fig 2 shows that in phase 2, the K in KWL (i.e. 'What do I know?') question yields two cognitive products: activated prior knowledge and strategies used before, and personal definition of task (i.e. individuals' perceived profile of task). The variance in task definition may be attributable to the differences in internal cognitive conditions between them; the external task conditions each of them generated should be identical. This suggests that the variability of learner characteristics manifested in phase 1 presumably sets a base for accounting for the individual differences in learning performance and achievement in the subsequent phases of mobile learning. The above analyses show the importance of studying learner characteristics in theoretically understanding and empirically analysing student's cognition and behaviours when they are learning in a MLE.

In Winne's model, with self-generated perceptions of the task in phase 1, self-regulating learners in phase 2 are supposed to set their own learning goals, as shown in Fig 2. The individual's definition of task is assumed to set the boundary of one's goal setting mediated by self-efficacy (Pajares 2008), referring to one's confidence or belief about his or her capabilities of completing the task. For example, if a student believes the learning task is easy for her to complete, she would likely set a higher goal (e.g. to learn more content) than that when she defines the task as a difficult one. The second KWL question is 'What do I want to know'. KWL here functions as a metacognitive tool by which students visualize their learning goals they set for themselves based on their interpretations of the task. Goals set by the students often are linked to but not necessarily identical to instructional objectives presented by the teacher when they act as agents to self-regulate their own learning (Winne & Nesbit 2010). One of the basic assumptions of SRL is that learners play a proactive role in choosing the form and amount of instruction they need. This implies that an effective MLE should offer students some choices (i.e. learner autonomy) in self-directing their learning, including setting learning goals.

A crucial cognitive operation in phase 3 is monitoring the process of engagement by comparing the current state of learning with the goals set in phase 2. In this phase, the goals serve as standards for the students to metacognitively monitor the progress of learning. The built-in KWL scaffolds the students to monitor the current state of their cognitive process by asking themselves the question – 'what have I learned'. Comparing the answer to this question with the goals they set can yield their subjective judgement of learning (JOL) (e.g. How well have I learnt? Have I reached the goals yet?), functioning as an internal feedback about the amount and rate of progress towards goals (Butler & Winne

1995). This internal feedback plays a vital role as an inherent mechanism for all self-regulated activities in guiding the students to complete a task by metacognitive controlling their behaviours, cognition, and motivation (Butler & Winne 1995; Winne, 2001).

Besides the internal feedback generated by students' own metacognitive monitoring, the teachers and classmates could also provide external formative feedback because the teacher can access individuals' KWL and other artefacts in GoManage, an online management system affiliated to the MLE. The GoManage server allows students to upload and update their work every time when they synchronize their smartphones with the server and allows researchers and teachers to monitor and assess what the students have done with the task both in and out of class. In this sense, GoManage serves as a mix of self-regulatory (via KWL) agents and external regulatory agents (via the teacher's external feedback on KWL and other cognitive products). SRL research reveals that external regulatory agents play an imperative role in facilitating students' SRL when they are involved in complex and challenging learning tasks (Azevedo 2005).

According to Winne (2011), learners have three basic choices for exercising agency to metacognitively control their own cognitive processes. One is by transforming contextual conditions such as adjusting the time allocated to engage in the learning tasks. The second is choosing various learning content for study and for re-study. For example, the students can choose either the outline of a topic presented in the MLE (GoKnow™) or the entire text in the paper-based textbook when they need to review the content for a test. The third form of metacognitive control is selecting the ways and format of cognitive operations for processing information and knowledge. For example, in the MLE we designed, the students were allowed to demonstrate their understanding of a study topic (e.g. insects) by either doing a concept mapping or an animation or updating their KWLs. These choices were contingent on a number of learner characteristics such as their online judgement of the real-time state of learning, schematized and habitual regulatory strategies (so-called habit of mind), and situational-specific motivation (e.g. task value, self-efficacy). The ubiquity and mobility of mobile technologies offer the students a larger degree of freedom to exercise agency in self-regulating their own learning when compared with the conventional classroom-based, teacher-centred curriculum.

One indicator of the student's persistence of cognitive engagement in learning across various learning settings is thinking or engaging in a learning problem and accessing the Internet or MLE by using the smartphone outside the school. Persistence is one of the indicators of motivation (Schunk *et al*. 2008). For instance, when a student Isabel learnt that some of her classmates were keeping hamsters as pets, she wanted to find out more from them. So, she started recording hamster's activities with her smartphone during her leisure time, and she scrutinized closely the photos of the hamsters and conducted her own research online.

Isabel is an example of a student in which it is natural for her to switch between various learning settings (formal or informal) motivationally, metacognitively, and behaviourally, that is, to self-regulate their own learning. Although the advanced mobile technologies can technologically and physically provide the infrastructure of and the possibility for mobile learning, equipping students with SRL knowledge and skills is essential to realize this possibility.

Measuring mobile learning from the SRL methodological perspective

The central question regarding the measurement of SRL in mobile learning is how researchers and educators can validly and reliably obtain the empirical data about students' motivation, metacognition, and learning behaviours while they are involved in mobile learning across various settings. This is an attempt to meet one of the challenges facing mobile learning that Vavoula and Sharples (2009) mentioned, namely 'measuring the processes and outcomes of mobile learning' (p. 54).

Researchers in educational psychology have increasingly realized the limitations of self-reports, including post-study interview method as measures of SRL in real-time (Winne *et al*. 2002; Perry & Winne 2006; Schraw 2010) because self-reporting what and how learning unfolds (e.g. engaging with the mobile device on the bus or at home) is based on subjects' fallible memory. According to those studies, when researchers seek indicators about how learners use strategies and tactics while studying, self-report data may not be reliable, although they can reveal learners' perceptions about their learning experiences.

Zimmerman (2008) comprehensively discussed the second wave of research in SRL, which is methodologically aimed at the development of online measures of SRL processes in authentic contexts. The general idea behind the trace-based methodology is that computer-based learning provides environments that enable researchers to trace learners' processes by means of log files that automatically and unobtrusively record accurate, time-stamped events of how learners choose, and manipulate content while learning activities taking place (Winne *et al*. 2002; Perry & Winne 2006). Traces here refer to artefacts of observable students' actual cognitive actions automatically recorded in the log files while they engage in a task (e.g. KWL).

Our research project developed Quiet Capture, a software-based data gathering tool that enables researchers and teachers to unobtrusively collect the online data about what, when, and how individual students were engaged with using the MLE (Boticki & So 2010). For example, capturing the time-stamped device screenshots provides sequential, qualitative, contextual, and pictorial information about the content, appearance, and formation of student's artefacts that are created or edited in and out of classrooms. By classifying students' activities (cognitive operations) based on some criteria or coding scheme, this tool can provide the quantitative data about when and how long each individual works on each of those cognitive operations. For example, according to Clough *et al*. (2008), student activities when they are involved in a mobile learning process can be classified into several types of applications such as administration (e.g. calendar and scheduling), data collection (e.g. taking photos in a museum tour), and referential (e.g. Web browsing). We found that during the first year of the project, the students spent 46% of the time with using the smartphones in the referential activities and 30% of time in data collection. We can obtain data about when and how long each individual worked in any one of these applications during a given period of time (e.g. in or out of school). That tool revealed that 70% of time students used their smartphones happened in school and 30% of time out of school during the 2-year period of experiment. Figure 3 provides an example of Isabel's out-of-school activities stored in the smartphone in which the exact date and time can be seen when that action was done.

Fig 3 An instance of students' artefacts captured by Quiet Capture.

A sample of our empirical work in applying SRL to analyse mobile learning

Next, we present some results of our empirical work to manifest how mobile learning processes can be understood and analysed under a framework of SRL. As introduced already, each student in the two classes involved in the project was equipped with a HTC smartphone. In 2010, the two classes of students spent 5 weeks studying the topic of magnets. After data screening, there are 68 valid subjects in total (39 males and 29 females).

During the 5-week lessons, a 5-point Likert survey was administered in the two classes. It measures three motivational variables (i.e. self-efficacy, intrinsic motivation, and extrinsic motivation) and one metacognitive variable (e.g. strategic regulation of learning). This SRL instrument was developed on the basis of the aforementioned motivated strategies for learning questionnaire (Pintrich *et al*. 1993; Duncan & McKeachie 2005). Each subscale has six items. All the items in this survey questionnaire are directly defined in the context of learning a specific scientific concept – magnet. For example, a self-efficacy item is 'I believe I am able to learn well the concept of magnet'; an intrinsic motivation item is 'Even when completing the assignments does not guarantee that I get a good grade, I still love to complete them'. Based on the initial reliability analysis and exploratory factor analysis, the number of items in each subscale is adjusted to 3. The internal consistency reliability (Cronbach's α) of each adjusted subscale exceeds.

During the 5-week lessons on the magnet, the teachers encouraged but did not require the students to fill in the KWL table in their mobile devices. In other words, each student had a choice in controlling their motivational and metacognitive behaviours by setting their goals of learning and monitoring the state of learning. In this sense, they were conditioned in a self-regulated mobile learning. Each of them either completed a KWL or did not. Accordingly, 68 students could be grouped into two categories denoted as a categorical dependent variable having two values: having KWL or having no KWL. The GoManage server indicated that half of the 68 students (34) completed KWL and half of them did not. This measure essentially samples each student's actual performance in using the mobile device as a metacognitive tool (i.e. metacognitively monitoring the state of learning via KWL) in the processes of mobile learning. In this sense, this is a process-oriented measure on an aspect of students' actual pattern of learning.

We have two kinds of empirical data from those students and their learning processes: self-reported SRL and actual SRL occurring in the context of mobile learning. The former was obtained from a self-report survey conducted during their learning processes. The latter was unobtrusively captured as server log file data. To examine the correlation between them, a logistic regression analysis was conducted. The findings show that among the four self-reported SRL measures, extrinsic motivation can statistically predict whether or not the students completed the KWL during the 5-week lessons on magnet [$\chi^2(1,68) = 5.632$, $\alpha = 0.018$], that is to say, the difference between the two groups of students (having KWL vs. having no KWL) on extrinsic motivation is statistically detectable. Specifically, the group of students who did not complete KWL has a higher mean score of extrinsic motivation. Our finding is that in this case the higher extrinsic motivation a student had, the less likely he or she completed KWL given he or she had a choice to do so. Extrinsic motivation reflects one's purpose of involving in a learning task is to attain a high grade or to please others (e.g. parents, teachers). For example, in our SRL survey, the items measuring extrinsic motivation are stated as: 'Getting a good exam score on the concepts of magnet is the most satisfying thing for me right now', 'I normally will only learn the concepts that will be tested even though they are much interesting to me'.

A tentative interpretation of this empirical finding is that when the students in the two classes had a choice in doing KWL and realized it is not directly associated with their exam scores, the students with high extrinsic motivation tended to ignore KWL and those with low extrinsic motivation tended to complete it. The preliminary result of our empirical work is an illustration of how SRL theories (e.g. motivational constructs) and methodology (e.g. a combination of self-report method and unobtrusive log file data) can help us analyse and understand a mobile learning process (e.g. working with KWL in the mobile devices).

Conclusion

Sharples *et al*. (2005, 2007) recognized four criteria for a theory of mobile learning, two of which are highlighted here. First, a theory of mobile learning should grasp the unique characteristic of mobile learning that qualitatively differentiates this type of learning from other types of conventional learning activities such as other types of e-learning (e.g. using desktops or laptop computers). The central assumption of mobile learning is that learners are continually in motion – ubiquity. They can learn across time and space.

A significant challenge facing mobile learning researchers is that in addition to equipping students with personal, portable, mobile devices, and mobilized curricula, what else is needed for fostering effective student-centred, personal, and ubiquitous learning. This elicits the second imperative criteria for a theory of mobile learning. A theory of mobile learning must embrace the contemporary accounts of the considerable factors underlying successful lifelong learning due to the inherent relationships between mobile learning and lifelong learning. Thus, the issue becomes: what are the contemporary theories of learning needed for this purpose.

The present study takes our current work in developing and implementing a MLE in elementary science classes in Singapore as the informative context in which how the theories and research methodology of SRL can help us better understand and analyse the mechanism and processes of mobile learning. It is evident that when

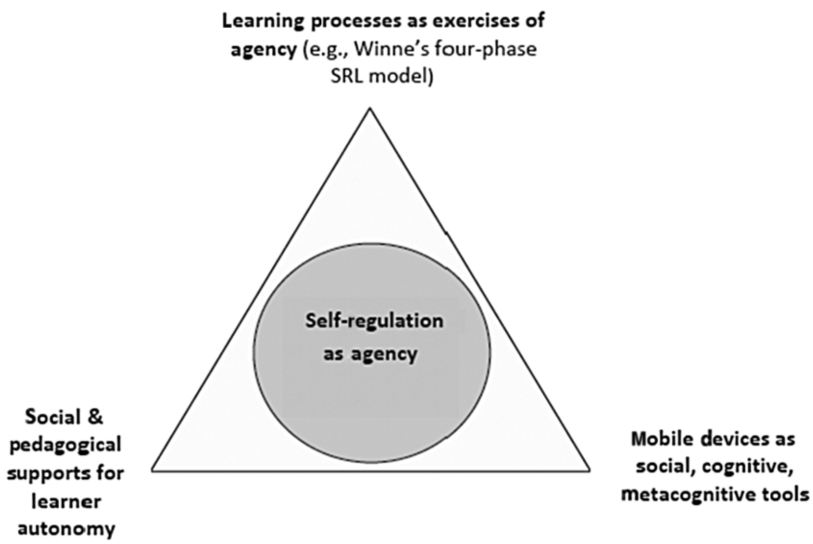

Fig 4 An analytic self-regulated learning (SRL) model of mobile learning.

learners are motivationally, metacognitively, and behaviourally engaged in the learning activities, i.e. self-regulate their own learning, they are not only yet led to 'water' (mobile learning spaces) by means of mobile technologies and devices but also are able to proactively and strategically 'drink' (acquiring and constructing knowledge) the right amount of water at the right time.

Putting the above together, we conclude an analytic SRL model (see Fig 4) for designing and analysing mobile learning. At the centre of the model is the notion of self-regulation as agency, referring to the learner characteristics that function as internal driving forces initiating and sustaining a self-regulated mobile learning process. The key learner characteristics include domain knowledge, prior experiences, motivation, and metacognitive awareness, epistemological beliefs, and so on. First, mobile learning processes that are regarded as manifestation/exercises of agency can be understood and analysed by means of SRL theories (e.g. Winne's four-phase model) and methodologies (e.g. self-report survey, trace analysis).

Second, mobile learning activities are supposed to be mediated by mobile technologies and devices, which presumably function as social, cognitive, and metacognitive tools. Learners produce various types of artefacts that are viewed as externalization and visualization of their cognition and metacognition, as well as communication with others. Student artefacts in this project include learning goals (motivation) and JOL (metacognitive monitoring) by KWL, animations by Sketchy™, and concept maps by Picomap™. Animations and concept maps are the visualizations of students' conceptions of the scientific concepts they are studying in the mobilized curriculum.

Third, in the light of SRL, the key to pedagogical design is to offer learners some degree of freedom (i.e. learner autonomy) in setting goals, monitoring and controlling learning processes (e.g. selecting tasks, strategies, and study time), assessing, and evaluating learning activities. The key idea of this model is that while the advanced mobile technologies and devices provide the technological and physical infrastructures for mobile and ubiquitous learning, learners' SRL knowledge and skills are essential to realize this possibility.

Research in educational psychology has produced prolific findings about factors that influence and correlate with academic achievement (Winne & Nesbit 2010). Based on this, they identify two domains of psychology. One is 'heuristics that describe generic relations between instructional design and learning' (p. 653) – 'the way things are'. The other is the psychology of 'the way learners make things'. Research in metacognition and SRL falls into this school in which learners are viewed as agents that choose whether and how to engage in tasks. The above anaysis has shown that as an instance of the latter, SRL can explain whether and how students selectively work with the features (e.g. KWL in our project) a MLE offers by exercising control over their cognition and actions. Meanwhile, the understanding of the ubiquity of mobile learning is in accordance with the contemporary view of cognition that cognition is not only situated (Robbins & Aydede

2009), but dynamic and self-organized (Tschacher & Scheier 1999; Smith 2005).

This paper is an initial effort to expand and enrich the knowledge about mobile learning within the framework of self-regulated learning. One of the largest challenges in this course will be how SRL can be systematically and institutionally applied to curriculum development, instructional design, teacher professional development, and teaching and assessment practices in classrooms that foster student-centred lifelong learning.

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References

Azevedo R. (2005) Using hypermedia as a metacognitive tool for enhancing student learning? The role of self-regulated learning. *Educational Psychologist* **40**, 199–209.

Bandura A. (1986) *Social Foundations of Thought and Action: A Social Cognition Theory*. Prentice-Hall, Englewood Cliffs, NJ.

Bandura A. (2001) Social-cognitive theory: an agentic perspective. *Annual Review of Psychology* **52**, 1–26.

Boekaerts M. (1997) Self-regulated learning: a new concept embraced by researchers, policy makers, educators, teachers, and students. *Learning and Instruction* **7**, 161–186.

Boekaerts M. & Corno L. (2005) Self-regulation in the classroom: a perspective on assessment and intervention. *Applied Psychology: An International Review* **54**, 199–231.

Boticki I. & So H.-J. (2010) Quiet Capture: A tool for capturing the evidence of seamless learning with mobile devices. Proceedings of the 9th International Conference of the Learning Sciences, Chicago, 29 June–2 July 2010.

Butler D. & Winne P.H. (1995) Feedback as self-regulated learning: a theoretical synthesis. *Review of Educational Research* **65**, 245–281.

Carver C.S. & Scheier M.F. (1998) *On the Self-Regulation of Behavior*. Cambridge University Press, New York, NY.

Chen W., Tan N.Y.L., Looi C.-K., Zhang B. & Seow P.S.K. (2008) Handheld computers as cognitive tools: technology-enhanced environmental learning. *Research & Practice in Technology Enhanced Learning* **3**, 231–252.

Clough G., Jones A.C., McAndrew P. & Scanlon E. (2008) Informal learning with PDAs and smartphones. *Journal of Computer Assisted Learning* **24**, 359–371.

Duncan T.G. & McKeachie W.J. (2005) The making of the motivated strategies for learning questionnaire. *Educational Psychologist* **40**, 117–128.

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

Kistner S., Rakoczy K., Otto B., Dignath-van Ewijk C., Büttner G. & Klieme E. (2010) Promotion of self-regulated learning in classrooms: investigating frequency, quality, and consequences for student performance. *Metacognition and Learning* **5**, 157–171.

Koriat A. (2007) Metacognition and consciousness. In *The Cambridge Handbook of Consciousness* (eds P.D. Zelazo, M. Moscovitch & E. Thompson), pp. 289–325. Cambridge University Press, New York, NY.

Liaw S.-S., Hatala M. & Huang H.-M. (2010) Investigating acceptance toward mobile learning to assist individual knowledge management: based on activity theory approach. *Computers & Education* **54**, 446–454.

Looi C.-K., Seow P., Zhang B.H., So H.-J., Chen W. & Wong L.-H. (2010) Leveraging mobile technology for sustainable seamless learning: a research agenda. *British Journal of Educational Technology* **41**, 154–169.

Looi C.K., Zhang B., Chen W., Seow P., Chia G., Norris C. & Soloway E. (2011) 1:1 mobile inquiry learning experience for primary science students – a study of learning effectiveness. *Journal of Computer Assisted Learning* **27**, 269–287.

Martin J. (2004) Self-regulated learning, social cognitive theory, and agency. *Educational Psychologist* **39**, 135–145.

Nelson T.O. (1999) Cognition versus metacognition. In *The Nature of Cognition* (ed. R.J. Sternberg), pp. 625–641. The MIT Press, Cambridge, Massachusetts.

Norris C. & Soloway E. (2008) Getting mobile handhelds help bring k-12 classrooms into the 21st century. District Administration Magazine, Available at: http://www.districtadministration.com/ (last accessed 11 October 2010).

Ogle D.M. (1986) K-W-L: a teaching model that develops active reading of expository text. *Reading Teacher* **39**, 564–570.

Pajares F. (2008) Motivational role of self-efficacy beliefs in self-regulated learning. In *Motivation and Self-Regulated Learning: Theory, Research, and Applications* (eds D.H. Schunk & B.J. Zimmerman), pp. 111–139. Lawrence Erlbaum Associates Publishers, Mahwah, NJ.

Peng H., Su Y.-J., Chou C. & Tsai C.-C. (2009) Ubiquitous knowledge construction: mobile learning re-defined and a conceptual framework. *Innovations in Education & Teaching International* **46**, 171–183.

Perry N.E. & Winne P.H. (2006) Learning from Learning Kits: gStudy traces of students' self-regulated engagements with computerized content. *Educational Psychology Review* **18**, 211–228.

Pintrich P.R., Smith D.A., Garcia T. & McKeachie W.J. (1993) Reliability and predictive validity of the motivated strategies for learning questionnaire (MSLQ). *Educational and Psychological Measurement* **53**, 801–813.

Robbins P. & Aydede M. (2009) *The Cambridge Handbook of Situated Cognition*. Cambridge University Press, New York, NY.

Ryan R.M. & Deci E.L. (2000) Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist* **55**, 68–78.

Schober B., Finsterwald M., Wagner P., Lüftenegger M., Aysner M. & Spiel C. (2007) TALK – a training program to encourage lifelong learning in school. *Zeitschrift für Psychologie* **215**, 183–193.

Schraw G. (2010) Measuring self-regulation in computer-based learning environments. *Educational Psychologist* **45**, 258–266.

Schunk D.H. & Zimmerman B.J. (2008) *Motivation and Self-Regulated Learning: Theory, Research and Applications*. LEA, New York, NY.

Schunk D.H., Pintrich P.R. & Meece J.L. (2008) *Motivation in Education: Theory, Research, and Applications*, 3rd edition. Pearson Education Inc., Upper Saddle River, NJ.

Sharples M., Taylor J. & Vavoula G. (2005) Towards a theory of mobile learning. Proceedings of mLearn 2005 Conference, Cape Town.

Sharples M., Taylor J. & Vavoula G. (2007) A theory of learning for the mobile age. In *The Sage Handbook of E-Learning Research* (eds R. Andrews & C. Haythornthwaite), pp. 221–245. Sage, London.

Smith L.B. (2005) Cognition as a dynamic system: principles from embodiment. *Developmental Review* **25**, 278–298.

Tschacher W. & Scheier C. (1999) The perspective of situated and self-organizing cognition in cognitive psychology. In *The Nature of Concepts: Evolution, Structure and Representation* (ed. P. Van Loocke), pp. 68–90. Taylor & Frances/Routledge, Florence, KY.

Vavoula G. & Sharples M. (2009) Meeting the challenges in evaluating mobile learning: a 3-level evaluation framework. *International Journal of Mobile and Blended Learning* **1**, 54–75.

Vogel D., Kennedy D. & Kwok R.C.-W. (2009) Does using mobile device applications lead to learning? *Journal of Interactive Learning Research* **20**, 469–485.

Wali E., Winters N. & Oliver M. (2008) Maintaining, changing and crossing contexts: an activity theoretic reinterpretation of mobile learning. *ALT-J: Research in Learning Technology* **16**, 41–57.

Waycott J., Jones A. & Scanlon E. (2005) PDAs as lifelong learning tools: an activity theory based analysis. *Learning, Media & Technology* **30**, 107–130.

Winne P.H. (2001) Self-regulated learning viewed from models of information processing. In *Self-Regulated Learning and Academic Achievement: Theoretical Perspective* (eds B.J. Zimmerman & D.H. Schunk), pp. 153–189. Longman, New York, NY.

Winne P.H. (2011) A cognitive and metacognitive analysis of self- regulated learning. In *Handbook of Self-Regulation of Learning and Performance* (eds B.J. Zimmerman & D.H. Schunk), pp. 15–32. Routledge, New York, NY.

Winne P.H. & Nesbit J.C. (2010) The psychology of academic achievement. *Annual Review of Psychology* **61**, 653–678.

Winne P.H., Jamieson-Noel D.L. & Muis K. (2002) Methodological issues and advances in researching tactics, strategies, and self-regulated learning. In *Advances in Motivation and Achievement: New Directions in Measures and Methods*, Vol. 12 (eds P.R. Pintrich & M.L. Maehr), pp. 121–155. JAI Press, Greenwich, CT.

Zhang B., Looi C.-K., Seow P., Chia G., Wong L.-H., Chen W., So H., Norris C. & Soloway E. (2010) Deconstructing and reconstructing: transforming primary science learning via a mobilized curriculum. *Computers & Education* **55**, 1504–1523.

Zimmerman B.J. (2008) Investigating self-regulation and motivation: historical background, methodological developments, and future prospects. *American Educational Research Journal* **45**, 166 –183.

Zimmerman B.J. & Schunk D.H. (2001) Reflections on theories of self-regulated learning and academic achievement. *Self-Regulated Learning and Academic Achievement: Theoretical Perspectives*, 2nd edition (eds B.J. Zimmerman & D.H. Schunk), pp. 289–307. Lawrence Erlbaum Associates Publishers, Mahwah, NJ.

Zurita G. & Nussbaum M. (2007) A conceptual framework based on Activity Theory for mobile CSCL. *British Journal of Educational Technology* **38**, 211–235.